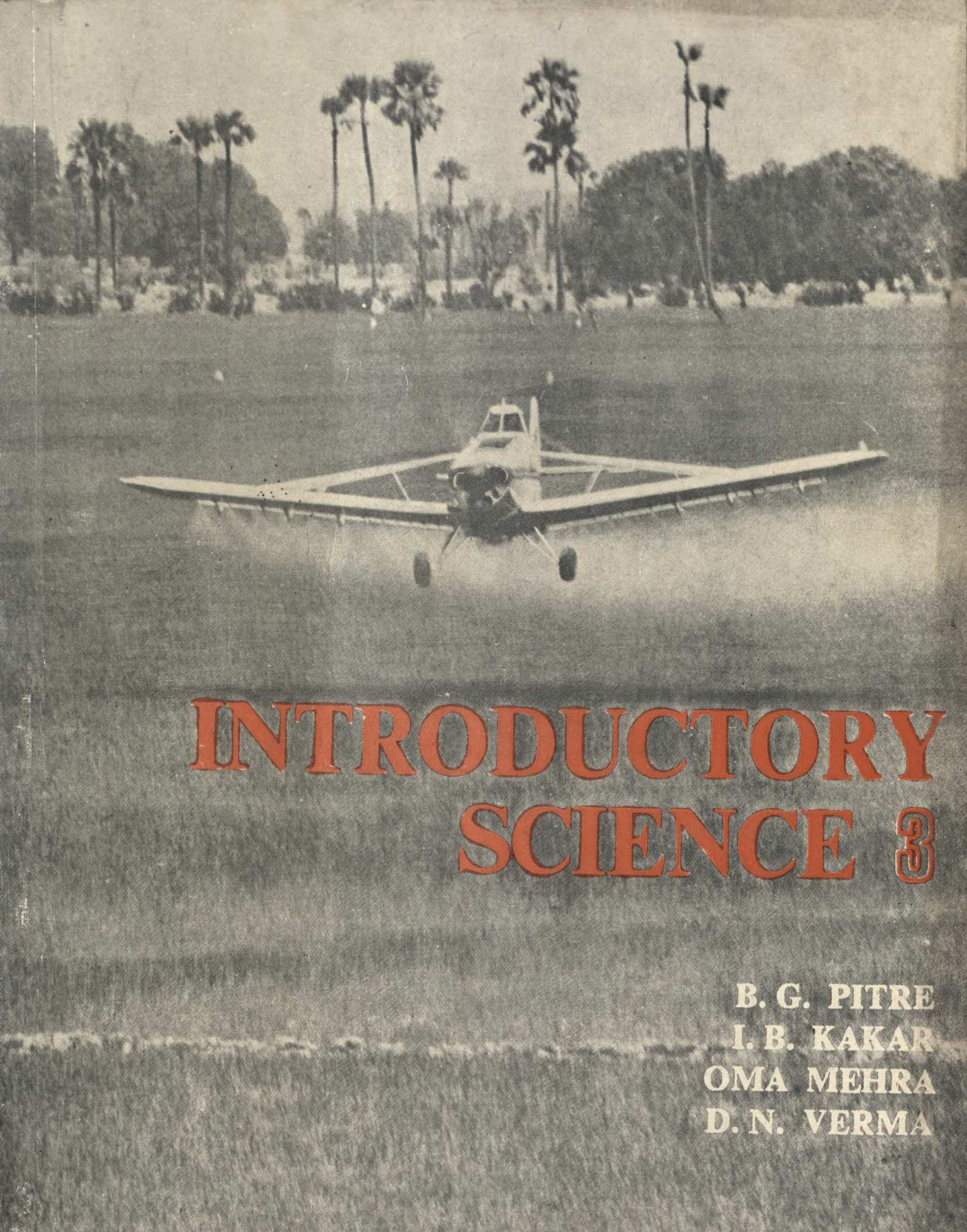

INTRODUCTORY SCIENCE 3

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A Modern Approach

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Orient Longman

Introductory Science 3

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16-A Ashok Marg, Lucknow 226 001

Cover Photo : Courtesy USIS

Acc No— 16480

First Published 1976
Reprinted 1979, 1982, 1983, 1984, 1985, 1986, 1987, 1988

ISBN 0 86125 509 7

Published by
Orient Longman Limited
1/24 Asaf Ali Road
New Delhi 110 002

Printed in India at
Jupiter Offset Press
10/3-B, Jhilmil Industrial Area
Shahdara, Delhi 110 032

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To the Teacher

In the past decade we have witnessed a number of attempts to revise curriculum and rewrite science texts for the Junior High School classes. Opinion among science educators all over the world seems to oscillate between two extreme positions—an integrated, thematic approach which most teachers find insufficiently equipped to teach, and a separate disciplined approach which is in vogue at present in our country.

It has been the cherished dream of all science educators to conceive a unified science curriculum which enables students to appreciate science as a human endeavour influencing our society, culture and daily life, and to implement it in an integrated fashion providing glimpses of skills, techniques and concepts which form the very core of all scientific activity. Several attempts have been directed to develop new materials on the assumption that the syllabus prescribed by various educational Boards will fall in line, and that the introduction of these texts and kits in schools would significantly improve the teaching of science.

One does not need a second opinion to be convinced that the availability of new materials has had little qualitative impact on actual classroom teaching. Many reasons have been given for this state of affairs. Nevertheless, it can be safely assumed that besides a syllabus and the examination system, the texts and the teachers who use them in their classes form the vital links between a dream and its realisation.

The authors have written these texts based on their wide and deep experience in teaching and working in collaboration on several approaches to science teaching. These texts in three volumes cover approximately the three-year course in science at the middle school stage in English medium schools. The authors hope that the texts will commend themselves in providing sufficient knowledge for an intelligent appreciation of the modern progress in science, while creating a broad unified background and a strong foundation to serve as a preparatory course for the three specialised disciplines at the secondary stage.

In offering these texts to the pupils, the following considerations have weighed upon our minds:

(*a*) Theory should be sufficiently interspersed with practical activity in the development of a topic. Many experiments and demonstrations have therefore been suggested so that students may be guided to conclude and form concepts based on the observation and interpretation of the experiments.

(*b*) Lengthy explanations, unnecessary mathematical derivations and irrelevant taxonomical details should be avoided in a first-acquaintance presentation to science. Problems, both theoretical and numerical, have therefore been included with an aim to show further applications of the principles rather than to engage pupils in repetitive work.

(*c*) Next to a first hand experience of apparatus and phenomena, clear illustrative diagrams and photographs are the best aids to a proper assimilation of the subject, and of its extension to technology and environment in the out-of-school world. No time and effort has been spared to equip the text with illustrations.

Concept development in students is a gradual, cumulative process; the sequence of topics should therefore be psychological rather than logical. The unconventional presentation of course content in these texts enables a lot of good science to be taught in an economical and efficient way. It has been successfully trial-tested for several years by the authors and their colleagues, yet it gives the teacher a relatively free choice to select his own sequence

The authors realise that there is no unique way to teach a subject. Moreover, a first attempt to present it in a book form lacks refinement. It would therefore be appreciated if they receive critical comments and suggestions from teachers who actually use the texts in their classrooms.

B.G. PITRE
July 24, 1976 *General Editor*

1

Reflection of Light

A non-luminous object could be transparent, opaque or translucent. When light falls on it, one or more of the following may happen : (*a*) light may pass through the object; (*b*) light may be absorbed; or (*c*) light may bounce off the object.

You cannot see through an opaque object; however, it is easy to see an opaque object because it scatters sufficient light. A bright looking object throws back more light than a dull looking object, while a dull object absorbs more light than a bright object. Transparent objects such as air and clean window panes cannot be seen because they do not throw back much light towards you; however, you can see right through such materials. Thus, transmission, absorption or reflection appear to be a property of the objects upon which light falls.

For most of the practical work we require some apparatus which produces a narrow beam or a ray of light; let us call such an apparatus a ***"light box"***.

REFLECTION

Activity 1. Spread a white sheet on top of a table in a dark room and place a light box at one end of the sheet. When light is switched on, you will notice the path of a beam of light made visible as it grazes along the sheet. Hold a narrow vertical slit in front of the beam so that a narrow beam of white light is obtained (diagram 1). If you now hold a strip of mirror vertically to obstruct the beam of light you will observe that the direction of the beam is changed by the mirror.

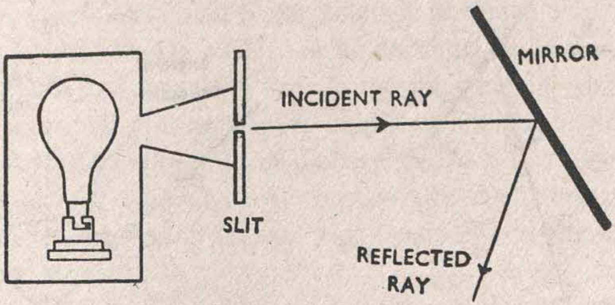
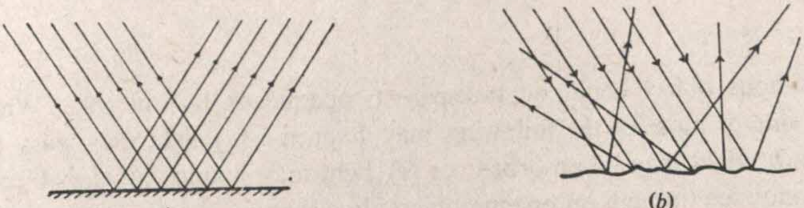


Diagram 1

The path along which light ray travels up to the mirror is called an ***incident ray****. The path along which the light travels away from the mirror is called the* ***reflected ray****.*

Deflect the mirror to various angles and notice how this changes the direction in which the reflected ray travels. Can you reflect the ray at a right angle to the incident ray? Can you reflect the ray back along its path? In every case you will observe that the reflected beam is not scattered all around but the whole of it bounces away in a particular direction; and the particular direction depends upon how the mirror is placed (diagram 2 *a*). This is called ***regular reflection.***


(*a*)
Regular reflection

(*b*)
Irregular reflection

Diagram 2

If the plane mirror is replaced by a metal sheet, you will see nore flected beam; the incident light is scattered in all directions (diagram 2*b*). This diffuse or ***irregular reflection*** is entirely due to unevenness of the surface on which light falls. We can feel the roughness of the surface, or see it by holding the metal sheet below a magnifying glass.

From the experiment it becomes obvious that regular reflection follows a certain pattern. Place a small white paper and draw on it a line *MP* along the mirror; next mark points *A* and *B* on the incident ray, and two other points *C* and *D* on the reflected ray as shown in diagram 3. Now remove the paper, join *A* and *B* by a line and *C, D* by another. Produce both the lines and you will get the incident and reflected rays meeting at a point on the mirror line *MP*.

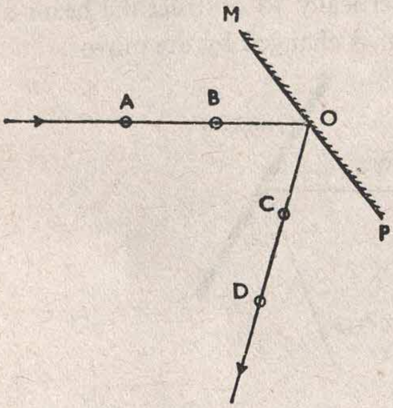


Diagram 3

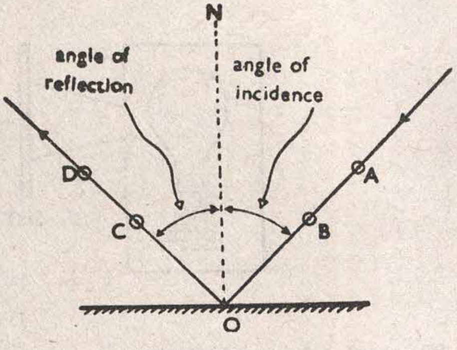


Diagram 4

The point *O* is called the ***point of incidence.*** Now use a protractor to measure the angles *AOM* and *DOP*. Repeat the experiment with different inclinations of the mirror to the incident ray, and obtain some more records. You will find that in all cases the two angles are almost equal.

LAWS OF REFLECTION

In practice, the angles selected are different. A line perpendicular to the mirror at the point of incidence O is drawn; this line ON (diagram 4) is called the ***normal***. The angle between the incident ray and the normal $\angle AON$ is called the angle of incidence; the angle between normal and the reflected ray $\angle NOD$ is called the angle of reflection. These angles for all the records obtained from the experiments are equal. Thus, the direction in which the reflected ray bounces back from the mirror is seen to be predictable, and this is called the first law of reflection:

The angle of incidence = the angle of reflection

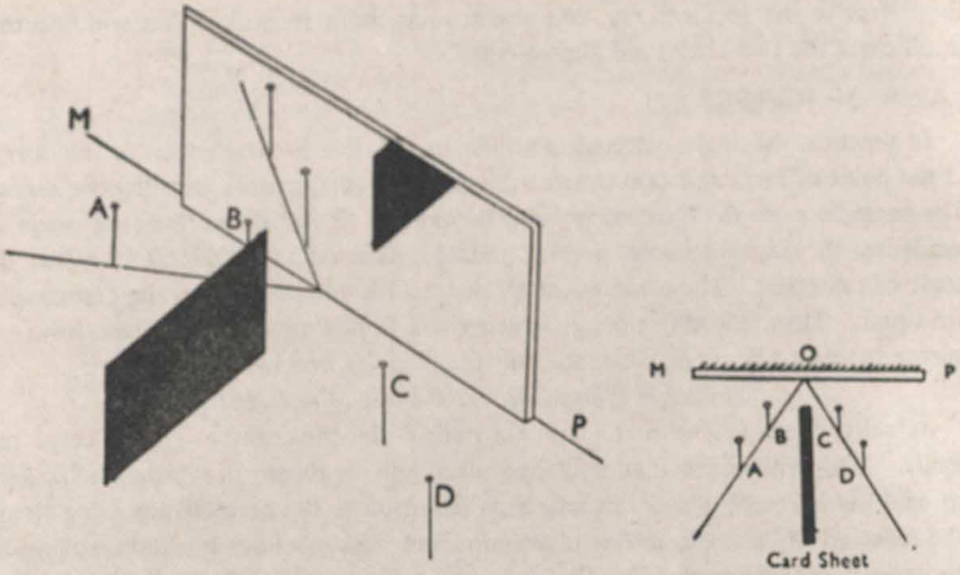
Actually, there is one more law which fixes the direction of the reflected ray firmly. You will notice that only one plane can be drawn in which the incident ray and the normal lie; and this plane passes through the point which joins them. The reflected ray also lies in this plane (which in this experiment was the plane of the paper), and passes through the point of incidence O. This fact is written as the second law of reflection:

The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane.

The light box usually gives a broad beam and it is not easy to draw a ray accurately. The same experiment can be performed using very simple apparatus and in broad day light.

Activity 2. Fix white sheet of paper on a soft board. Draw a line MP on the paper and stand a plane strip of mirror vertically along it. Now to fix the position of the incident ray we must mark at least two points. Therefore, two pins A and B are fixed vertically as markers about 5 cm apart such that a line joining them, which becomes the incident ray, is inclined at an angle to the mirror. Now place yourself on the other side and face the mirror in the direction in which you expect the reflected ray to come. It is convenient to hold a cardboard between your eyes and pins A, B so that you do not see them directly (diagram 5a); you will see the images of pins A and B in the mirror. With one eye closed, fix two pins C and D as markers for the reflected ray such that the pins C and D and the images of pins of A and B are in one straight line.

Now remove the mirror and the four pins. Join and produce AB to meet the mirror line MP at point O; join and produce CD to meet the mirror; this line should also meet the mirror line at point O. Draw normal ON and measure the angles of incidence and reflection. Repeat the experiment for different inclinations of AB. You will find that in all cases the angle of incidence is equal to the angle of reflection.



(a)

(b)

Diagram 5

IMAGE FORMED BY A PLANE MIRROR

When you look into a plane mirror every morning you are looking at your own image in it. When you fix a pin in front of a plane mirror, you can easily see its image from different positions of the eye. Even when you change the position of your eyes—forward, side-ways or backwards—the image position appears to remain fixed. Where is this image?

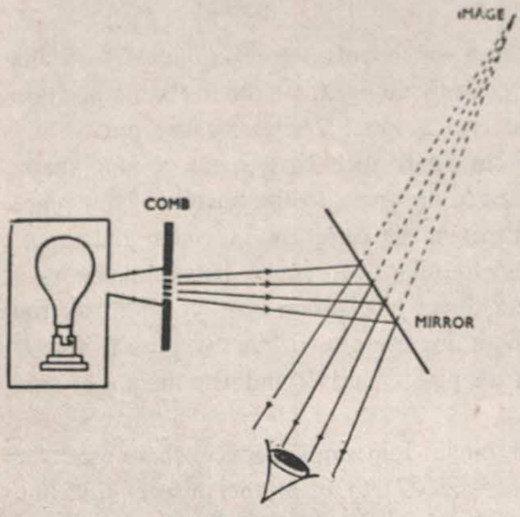


Diagram 6

Activity 3. Set up the light box again and fix a comb in front of it so that you see a fan of rays of light diverging outwards. From where do they start? How could you experimentally find out the position of the source? Place a plane mirror in the path of these diverging rays, and you will obtain the reflected rays as shown in diagram 6. If you look into the mirror against the reflected rays, you will get an impression that the rays are coming from a point behind the mirror. Actually the rays are coming from a point on the source in the light box, after getting reflected at the mirror. If the reflected rays are traced backwards, we obtain the point from where the rays appear to diverge; this point is called an image of the source. Two reflected rays are sufficient to locate the position of the image.

Activity 4. The image formed by a plane mirror can also be located with the help of pins. Fix a white sheet of paper on a soft board and stand a plane mirror vertically along a line *MN*. Fix a pin vertically at a point *S* which serves as an object. Fix another pin *A* so that *SA* becomes an incident ray. Obtain its reflected ray *CD* by fixing two pins. Similarly take another incident ray *SB* and trace its reflected ray *EF*. Now remove the mirror and the pins. Produce both the reflected rays *CD* and *EF* backwards (diagram 7) to obtain the point of intersection *I*, which is the image of *S*. Join *IS* and mark *O*, the common point on *IS* and *MP*. Measure the distance *IO* and *OS*, and the $\angle IOM$. You will find that $\angle IOM$ is almost a right angle, and $OI = OS$. Repeated experiments show that the perpendicular distances of the image and object from the mirror are equal. For example if you stand 1 metre away and in front of a plane mirror, your image will be 1 metre behind the mirror. Thus, *the image formed by a plane mirror is as much behind the mirror as the object is in front of it.*

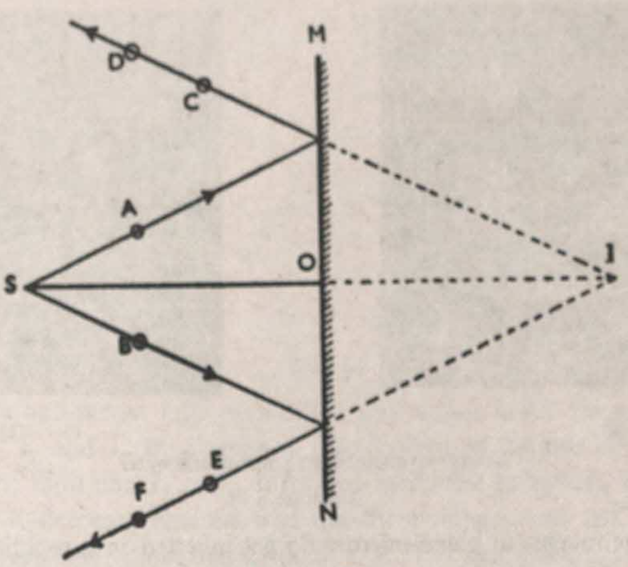
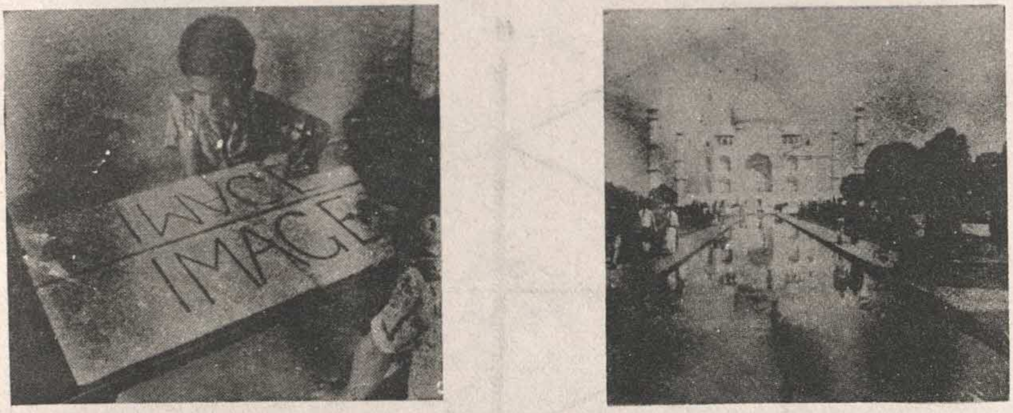


Diagram 7

VIRTUAL IMAGES

The image formed by a plane mirror appears very much like the object and gives an impression of sending out light which we receive. Actually, this image has no real existence and the light is coming directly from the object after reflection at the mirror surface. No light reaches the image and it cannot be taken on a screen. Such an image is called a ***virtual image***. In contrast, the image formed in a pin-hole camera is real; it is taken on a screen, light actually reaches there, and it scatters the light in all directions which is directly received by our eyes.

Activity 5. Hold a pencil in front of a plane mirror and you will notice that its image is as big as the pencil itself. Try it with a book, your fingers or any other object. In all cases you will find the size of the image by a plane mirror is the same as the size of the object. You also notice that the image seen in a plane mirror is upright, whereas the image in a pin-hole camera is inverted.



(a) (b)

Lateral inversion due to mirror and water

Diagram 8

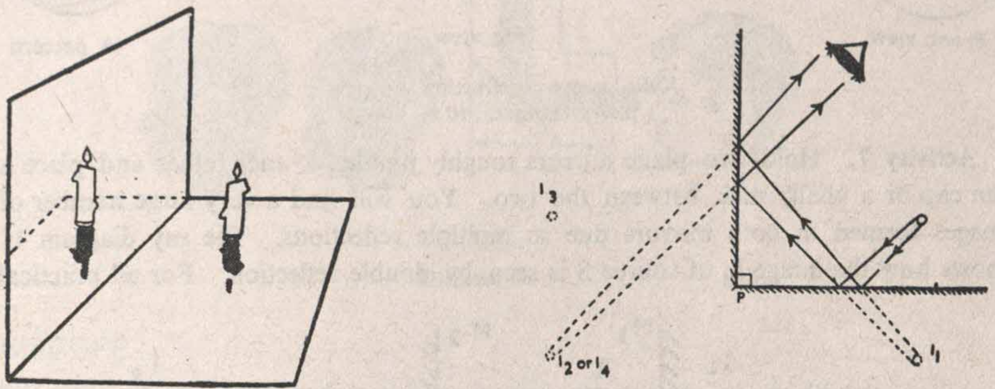
However, the images in plane mirrors do get inverted in a peculiar way. Stand in front of a plane mirror and raise your right hand to shake hand with your image. You will find that the image raises its left hand in response. If you write with your right hand, your image appears to be left handed (see photograph 8*a*). If some words on a paper are held close to a mirror, the image of the words appears reversed from side to side. This type of inversion is called ***lateral inversion.*** It is easy to see how this happens if you locate the corresponding image of each point of the object which is as much behind the mirror as the object is in front. To sum up, ***the image formed by a plane mirror*** has the following properties: *it is (a) virtual, (b) upright, (c) same size as the object, (d) laterally inverted, and (e) as far behind the mirror as the object is in front of it.*

MULTIPLE REFLECTIONS

One plane mirror gives one image of an object; how many images would we obtain with two plane mirrors? It is interesting to see the result when two mirrors are kept facing each other at different angles of inclination.

Activity 6. Stand upright a candle on a plane mirror strip and hold another mirror touching it at an angle of about 80° between them. How many images do you see? Now reduce the angle between the two mirrors gradually to 30°. Observe how the number of images changes.

When the angle between the two mirrors is 80°, you find four images in the two mirrors. As the angle is gradually increased from 80° to 90°, two of the images come together and merge into each other, and we see in all three images. Two of these images, I_1 and I_3 in diagram 9, are formed by the two mirrors by ordinary reflection. The third one, I_2 or I_4, is formed by double reflection. From geometrical construction it becomes obvious that the three images and the object form four corners of a rectangle whose middle point is P. The diagram shows rays originating from the object reaching the eye after reflections at each of the two mirrors, and appearing to come from the third image. It is also interesting to observe that the third image, because it is laterally inverted twice, is not inverted with respect to the object.



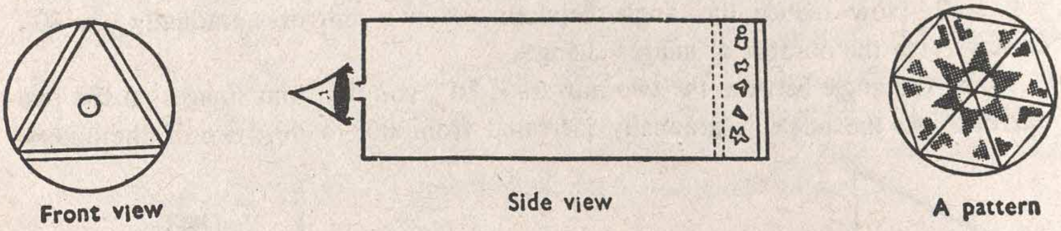
(a) (b)

Diagram 9

By a similar geometrical construction, it is possible to show that two mirrors inclined to each other at 60° will form five images. These five images and the object are all equidistant from the point P and therefore lie on a circle with P as the centre of the circle.

KALEIDOSCOPE

Kaleidoscope is an interesting toy which makes use of multiple reflection by plane mirrors held at 60° inclination. Three plane mirror strips of equal width and length are held tight inside a cardboard tube so that they are at 60° with one another. One side of the tube is blocked by coloured pieces of glass held between a transparent and a translucent glass plate, while the other end is blocked by a disc with a small hole to look inside. When we view through the tube against a bright background, the glass pieces and their images form beautiful coloured pattern which changes into innumerable designs as we rotate the tube.



Kaleidoscope construction and view
Diagram 10

Activity 7. Hold two plane mirrors roughly parallel to each other and place a pen cap or a chalk stick between the two. You will find a very large number of images formed in both mirrors due to multiple reflections. The ray diagram 11 shows how the image I_3 of source S is seen by double reflection. For all practical

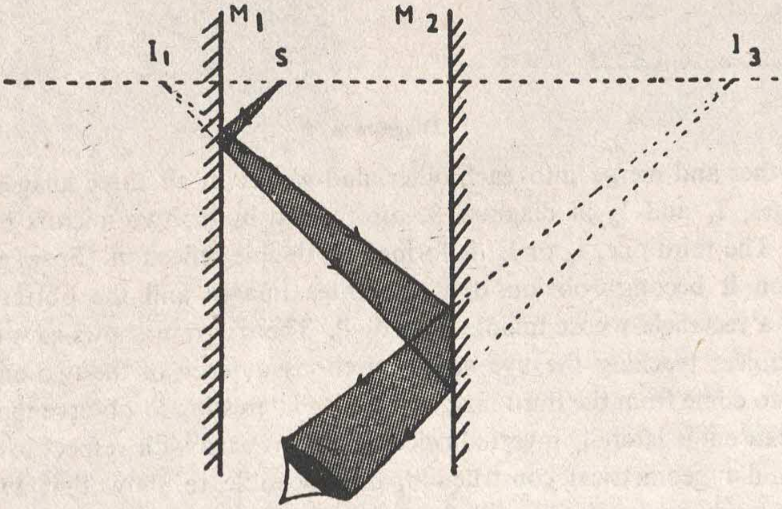
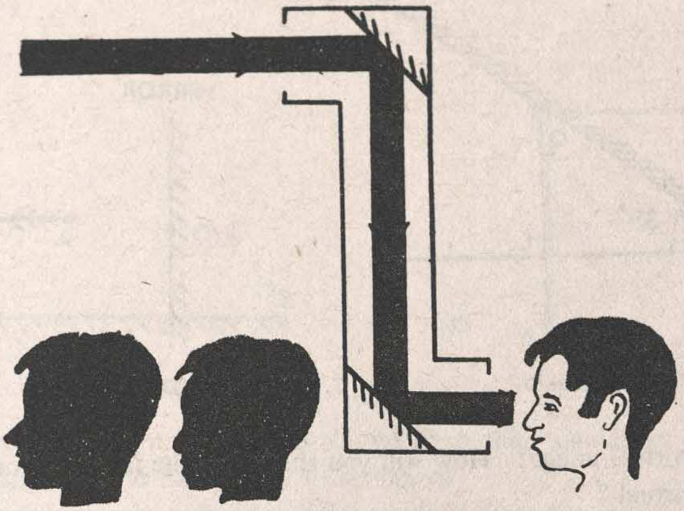


Diagram 11

purposes I_3 is the image of I_1 and is formed as much behind mirror M_2 as I_1 is in front of the mirror. If the eye were not to obstruct these rays, they will be reflected once again by the mirror M_1 and appear to come from an image of I_3 whose location will be as much behind M_1 as I_3 is in front of it. Thereby a series of images will result. However, such images will become less bright because of absorption of light at successive reflection. Barber shops often have mirrors facing each other fixed on opposite walls.



A Periscope

Diagram 12

PERISCOPE

If you stand in sun light with a mirror in your hand, you can easily reflect light into a dark room. By arranging a mirror suitably you can also see another person who is behind a wall. Similarly, by arranging two mirrors suitably it is possible to see over people's heads (diagram 12). Such an instrument is called a ***periscope.*** It contains two plane mirrors parallel to each other fixed in a tube in such a way that each deflects the incident rays of light by 90°. Such periscopes are also used by soldiers in trenches. Submarine periscopes are actually more complicated but essentially work on the same principle.

PROBLEMS

1. A plane mirror *AB* is standing vertically making an angle of 35° with a horizontal line *AC*. A ray of light *PQ* is incident on the mirror such that it cuts the line *AC* at a right angle (see diagram 13). Calculate the angle between the incident and the reflected rays.
2. *AB* is an arrow lying in front of a plane mirror. Take two incident rays from each of the points *A* and *B*, and show correctly the position of the image (see diagram 14). Explain how the image gets laterally inverted.

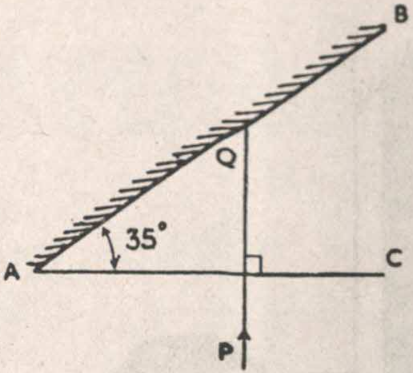


Diagram 13

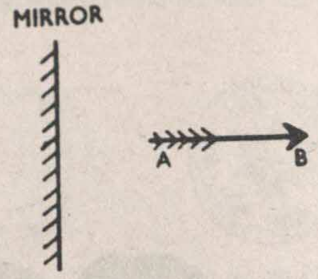


Diagram 14

3. What is a virtual image? How will you show that the image formed by a plane mirror is virtual ?
   If you look into a still pond of water, you can clearly see your own image in it. Is this a virtual image? What reason do you have for your answer?

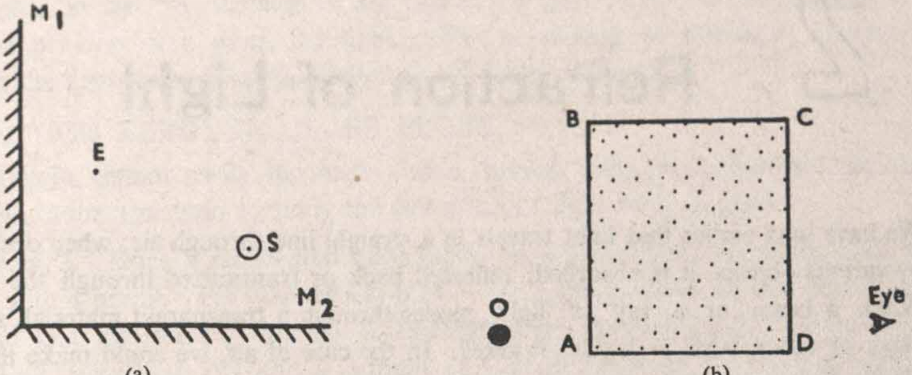
4. Write the various properties of an image formed by a plane mirror. Draw a line *AB* 2 cm high in front of a plane mirror. By constructing suitable rays and lines, locate the position of image as seen in an eye. Measure the height of the image.

5. A boy stands 2 m in front of a vertical plane mirror. Midway between him and the mirror is lying a football. How far is the football from him? If he steps back 1 m, how far will the image of the football be now from him?

6. Sitting in a chair in a barber's shop you can see the image of the back of your head. Explain with the help of a diagram the arrangement of mirrors necessary for this and show the path of light rays. Is the image laterally inverted?
   An object lies between two parallel plane mirrors 1 cm away from one and 1.5 cm from the other. Mark on a diagram clearly the positions of at least six images.

7. M_1 and M_2 are two plane mirrors held at right angles to each other (diagram 15 *a*). A source is placed 2 cm away from M_2 and 4 cm from M_1. The point *E* is 6 cm away from M_2 and 2 cm from M_1. Draw three incident rays from *S* so that after reflection they pass through *E*.

8. An object *O* is lying on one side of a block of wood whose four corners are *A*, *B*, *C* and *D* (diagram 15 *b*). Arrange two plane mirrors in line with *AB* and *CD* so that the image of the object can be seen clearly by the eye at *E*. How should these mirrors be arranged?



(a) (b)

Diagram 15

Arrange four mirrors near *A*, *B*, *C* and *D* so that the image can be seen. At what angle should the mirrors be arranged?

Is it possible to use only one mirror to see *O* from the eye?

2

Refraction of Light

We have seen earlier that light travels in a straight line through air; when obstructed by various objects, it is absorbed, reflected back or transmitted through the object. When a beam or a ray of light passes through a transparent material, such as glass or water, what path does it take? In the case of air, we could make the path visible by passing light through smoke or dust, or allowing it to graze along a white paper; how can we find out the path of light through water or glass?

REFRACTION

Activity 1. Adjust the "light box", with a narrow slit in front of it, on a white sheet of paper so that a narrow and bright beam of light is obtained along the paper. Darken the room and hold a rectangular glass trough filled with water in the path of the beam. Add to the water a few drops of milk or preferably a pinch of a chemical called "fluorescein". Look at the trough from the top.

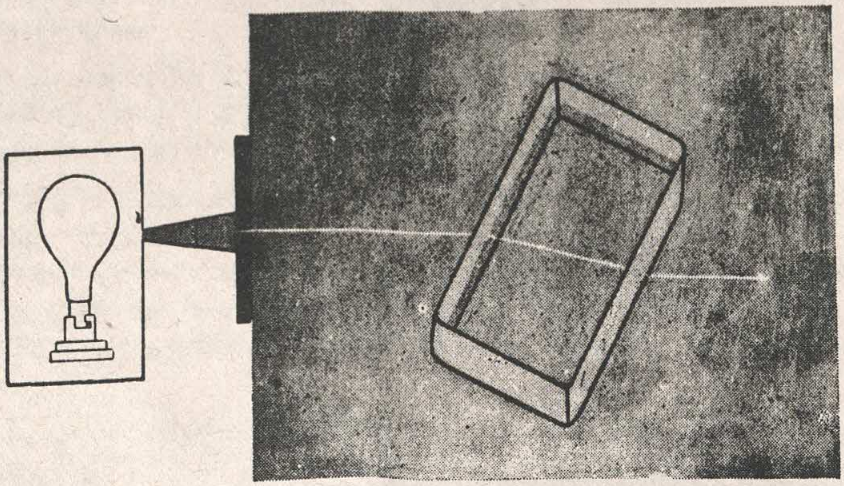


Diagram 16

You will notice that the beam bends away from its path as it enters the container, but follows a straight-line path in the water (diagram 16). *This bending of light as it goes from one medium to another is called* ***refraction.*** You will also observe partial reflection at the first surface of separation, and that the light is refracted a second time as it comes out of the container. Bending by refraction takes place at the two surfaces of separation. If you rotate the trough, you will find one position of it when the light suffers no change of direction; in such a position the light is incident ***"normally"*** on the water surface.

REFRACTION THROUGH GLASS BLOCK

Path of light cannot easily be made visible through solid glass; therefore, we have to use an indirect method to study the refraction of light through glass.

Activity 2. Place a rectangular glass block on a white sheet of paper; trace its outline with a pencil. Fix two vertical pins P and Q as markers on one side of the block so that the line PQ becomes a ray incident on the glass block. Remove the glass block, draw line PQ and a normal MN at the point A on which the ray is incident. It is desirable that the $\angle NAQ$ which is marked as the angle of incidence i, is not too small. Now replace the glass block properly along the outline.

Look from the other side and fix pins R and S as markers such that they are in line with the images of pins P and Q ***as seen through*** the block. Remove the block, produce RS to meet the outline of the block at B; and mark on it direction of light. This line is called the ***emergent ray***. The ray of light entered in the block at A and came out at B. It could be assumed that light travelled from A to B in a straight line; hence, join points A and B to obtain a straight line and mark direction on it. This line is called the ***refracted ray***.

Now measure the angle of incidence i, and the ***angle of refraction r***. You will notice that $\angle r$ is less than $\angle i$. This shows that when light enters a denser medium, it is refracted towards the normal. At B, when the ray AB emerges out into a rarer medium, the ray RS is seen to bend away from the normal.

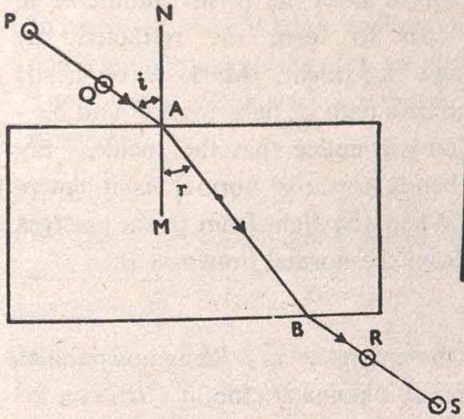


Diagram 17

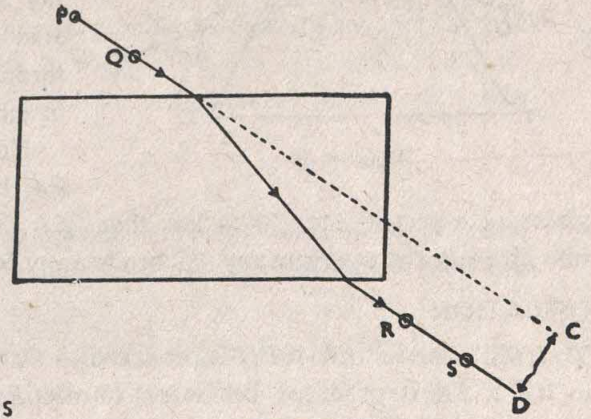


Diagram 18

DISPLACEMENT

Now produce line PQ upto C and check whether it is parallel to the emergent ray.

(How will you find this out?) While passing through the glass block, the ray got displaced from its original path but remained parallel to it. The distance CD (diagram 18) between the incident ray produced and the emergent ray is called the ***lateral displacement***.

Activity 3. Repeat the experiment with a glass block of greater thickness ***t***, and with different angles of incidence ***i***. You will find that the displacement increases with increase of ***t*** and ***i***, but in each case the emergent ray is parallel to the incident ray. In the event when the incident ray is normal on the glass block, *i.e.*, when the angle of incidence is zero, the ray passes straight through the block without displacement.

REFRACTION THROUGH PRISM

Let us study the path of a ray of light through glass when the two refracting surfaces are not themselves parallel to each other. For this purpose, a triangular glass block called a ***prism*** is taken; faces *XY* and *XZ* are the two refracting surfaces inclined to each other while the face *YZ* is called the ***base*** of the prism (diagram 19).

Activity 4. Draw outline of the prism on a white sheet, fix two pins *P* and *Q* to form the incident ray, and draw normal at A where the ray is incident on the face *XY*. With the prism in position, look from the side of face *XZ* towards the prism and fix pins *R* and *S* in line with images of *P* and *Q*. Remove prism and pins, and draw the emergent ray *SR* to meet the prism outline at B. Join *AB* to form the refracted ray through the prism. Mark arrow-heads to indicate path of light from *P* and *S*.

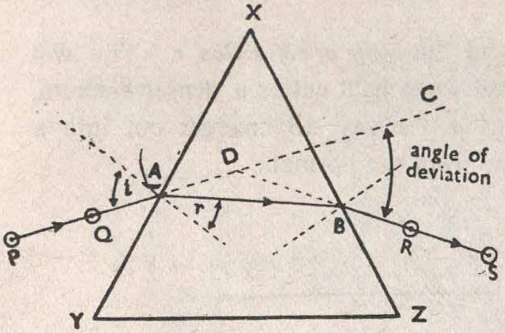


Diagram 19

You will notice that the incident ray *PA* bends towards normal as it enters glass; as expected, the $\angle r$ is less than $\angle i$. When the light from prism emerges into air at *B*, the emergent ray *RS* bends away from the normal drawn at *B*.

DEVIATION

You will observe that if *PQ* is produced to *C*, the emergent ray *RS* is not parallel to it. If *SR* is produced backwards to meet *PC* at a point *D*, the $\angle CDS$ can be measured. This angle between incident ray and emergent ray is called the ***angle of deviation***.

Activity 5. Repeat the experiment for the angle of incidence ***i*** varying between 30° and 70°. Measure and record the angle of deviation in each case. You will notice that as $\angle i$ increases, the angle of deviation at first decreases and increases again. There is therefore a minimum angle of deviation for the prism. If the experiment is repeated with prisms of different angles (of X), the angle of deviation will also be seen to depend on it: if $\angle X$ is less, the angle of deviation also becomes less.

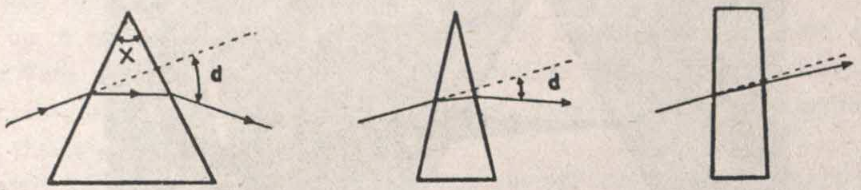


Diagram 20

The observations of these activities can now be summed up in the form of following rules, which would help to understand the phenomena of refraction:

(*a*) A ray of light going from a rarer into a denser medium bends towards the normal; the angle of refraction is less than the angle of incidence in this case.

(*b*) A ray of light emerging from a denser medium into rarer medium bends away from the normal; in such a case, the angle of emergence is more than the internal angle of incidence.

(*c*) When the incident ray is normal to the second medium, it is transmitted without change of direction; the angle of incidence and the angle of refraction are both zero.

(*d*) In case of parallel refracting surfaces (as in a glass slab), the incident and emergent rays are parallel to each other; the ray undergoes displacement without deviation.

(*e*) In case the two refracting surfaces are not parallel (as in a prism), the incident and emergent rays are not parallel to each other; the ray suffers deviation. The amount of deviation depends upon the angle between the two refracting surfaces.

DISPERSION

Rainbow in sky, reddish glow during sunset and different flowers make us realise the beauty in nature; we owe this to the nature of light and our sight. How is a rainbow formed?

Activity 6. Allow a very narrow beam of bright light from a "light box" to fall on one face of a prism. Hold a white screen on the other side so that light emerging out of the other face falls on it (diagram 21). You will see that the light has spread out into many colours on the screen. *The separation of light into its various components is called* ***dispersion.*** The spread out patch of light on the screen is called a ***spectrum.***

You will observe that the order of colours is the same as that seen in a rainbow, with the red bending least and the violet most. A rainbow is formed when rays of the sun refract through water particles suspended in air. The major rainbow colours which you may be able to detect are violet, blue, green, yellow and red, in that order. Thus, when a ray of light is refracted through a prism, it not only suffers deviation but also dispersion. The deviation is least for red and most for violet, in the case of any particular prism. Is it possible to recombine these colours?

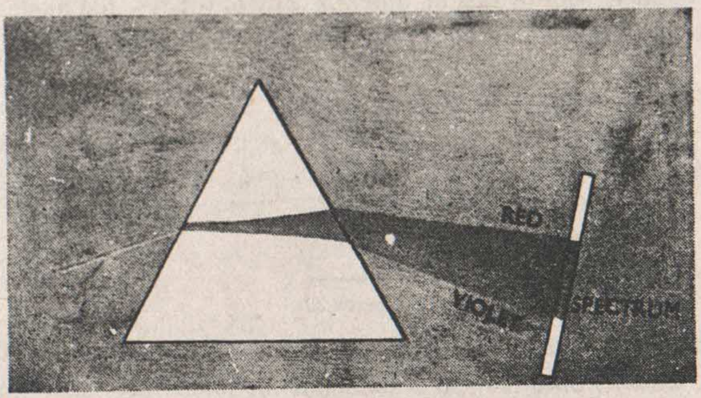


Diagram 21

Activity 7. Remove the screen and place a second prism with base upwards in the path of light. Make sure that the light emerging out of the first prism falls on a face of the second prism. The white screen is placed in the path of the light transmitted through the second prism, which will also need some adjustment. You will obtain on the screen a single beam of light without dispersion (diagram 22).

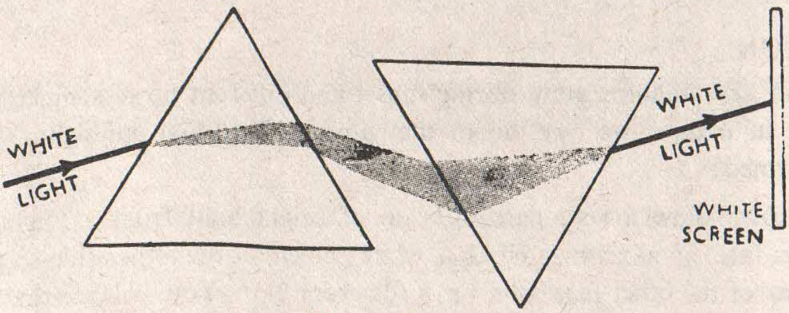


Diagram 22

The emergent light which is a combination of all the rainbow spectrum colours is called ***white light***. (Light itself is invisible; yet the term "white light" is in common usage. You should therefore clearly understand the meaning of this term.)

COLOUR OF OBJECTS

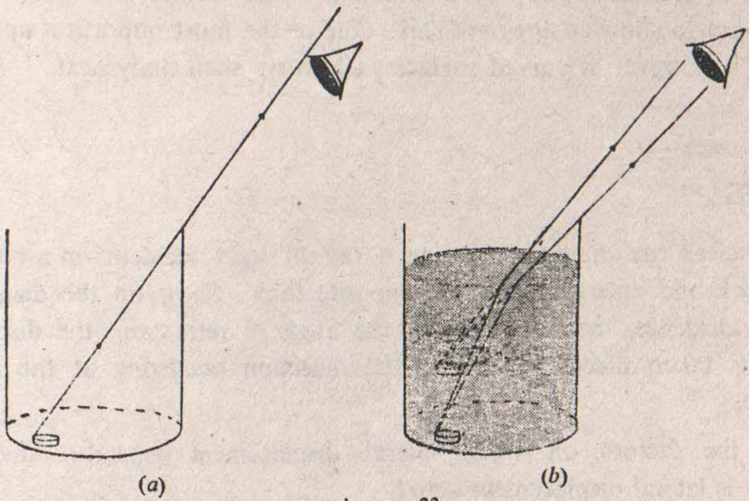
When light falls on an opaque object, part of it may be absorbed and the rest reflected; the reflected part gives the object its characteristic colour. When light falls on a transparent object, part of the light may be absorbed and the rest transmitted; the transmitted part gives the object its colour. Thus, incident light is ***selectively absorbed*** by an object, and the object appears to be of a colour depending upon the light that reaches our eyes.

If red light alone falls on a green leaf, the red light will be absorbed and the leaf will appear black. Thus the colour of an object not only depends upon the nature of its surface but also upon the light that falls on it. If a surface reflects all rainbow colours equally, its colour will appear white.

EFFECTS OF REFRACTION AT PLANE SURFACES

Because light rays suffer change of direction while going from one medium into another it appears to us that objects, when viewed through transparent materials, are in different positions than where they actually are. In other words we see the images of these objects.

Activity 8. Take an opaque container and place a coin at its bottom. Now position yourself such that the coin is not visible, just obstructed by the container (diagram 23 *a*). Now ask someone to gradually fill water in the container without disturbing the coin. You will observe that as the water level rises, the coin appears in sight.



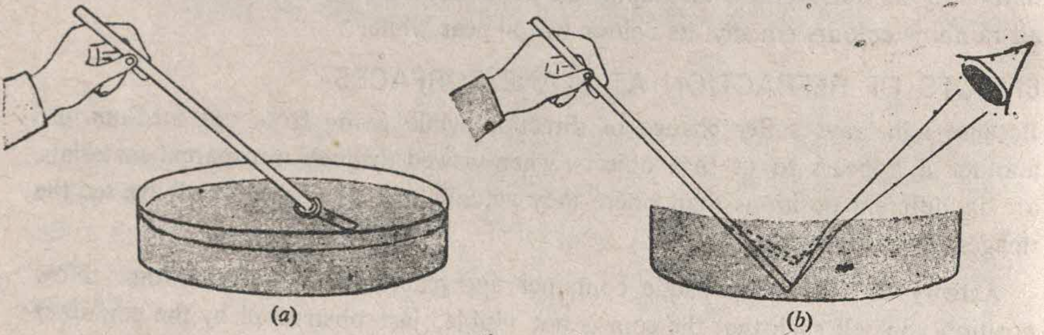
(*a*) (*b*)

Diagram 23

As the diagram 23 (*a*) shows, light from the coin is refracted away from the normal as it comes out of the water and reaches our eyes; as a result the rays appear to come from an image *I* of the coin. The coin at *C* appears to be at *I* giving us the impression that the water is shallower than what it actually is.

Activity 9. Fill a glass trough with water and dip a ruler in it obliquely (*i.e.*, not perpendicular to the surface of water). When you look at the ruler from the side through the trough, or from the top, it appears to be bent at the surface of water (diagram 24*a*).

Rays of light coming from the various points of the dipped part of the rod refract away from the normal as they emerge from water into air. For example, light from each point on the dipped part of the stick has a corresponding image point. The ruler therefore appears bent at the surface to our eyes.



(*a*) (*b*)

Diagram 24

There are several examples where refraction at the surface of a denser medium causes an object to show an apparent shift. One of the most important applications of refraction is however at curved surfaces, which we shall study next.

PROBLEMS

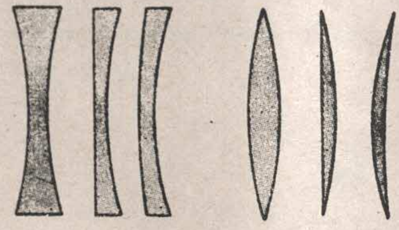
1. Draw a clear ray diagram showing a ray of light incident on a rectangular glass block and emerging from the opposite face. Show on the diagram: the angle of incidence, the refracted ray, the angle of refraction, the displacement which has taken place, and the partial reflection occurring at the point of incidence.
2. Explain the factors on which lateral displacement depends. Under what condition is lateral displacement zero?
3. With the help of a clear ray diagram show how deviation takes place during refraction in a triangular glass prism. On what factors does deviation depend?

4. Draw a clear ray diagram and explain how a ruler dipped slantingly in a trough containing water appears to be bent. Why does the bending disappear when the ruler is held normally dipped in water?
5. Draw a diagram to show how you would obtain a spectrum from sunlight using a prism. Name the colours in the correct order. Why do you normally not get a spectrum from a very broad beam of white light refracting through a prism?
6. Explain what you would see if only blue light falls on a (a) blue cloth, (b) white cap, and (c) a blue and white striped games shirt.

3

Experiments with Lenses

So far we studied examples of refraction where the surfaces of separation was plane. The most common example of refraction which is put to practical use is at a spherical surface: when we use a lens. *A lens is a refracting medium with at least one surface spherical.* Although there are many shapes (diagram 25) and sizes of lenses in use, essentially these are of two types: diverging and converging.


(*a*) Diverging lenses

(*b*) Converging lenses

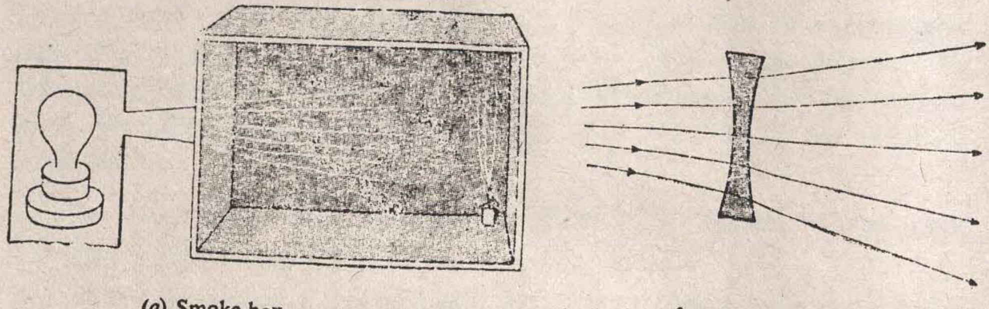
Diagram 25

DIVERGING LENS

A diverging lens can be recognised by feel of hand; as shown in diagram 25*a*, the lens is thin in the middle and thicker at the edge. If you look through a diverging lens, all objects will appear smaller.

The function of a diverging lens is to spread outwards (diverge) an incident beam of light. A useful apparatus to study this property is a "smoke box"; it can be improvised using the glass case of a physical balance. Its back, top and one side face are covered with black paper; the second side face is covered with black paper having a number of tiny holes.

Activity 1. Arrange a strong source of light so that rays enter the box through the holes in the black paper. A lot of smoke is created inside by burning a paper or incense. The smoke makes the ray of light visible, which can then be viewed through the front glass panel (diagram 26*a*). Now place a diverging lens inside


(*a*) Smoke box

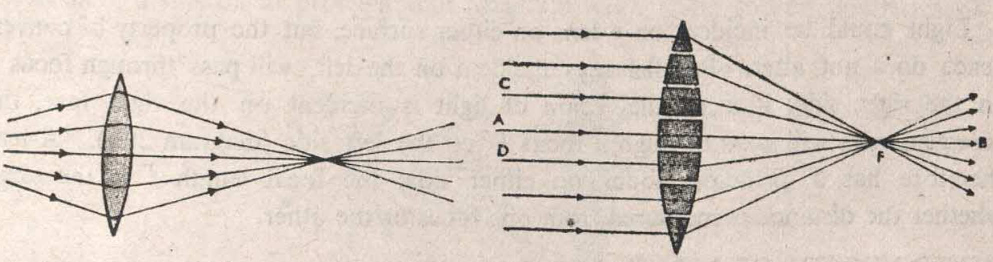
(*b*) Action of a diverging lens

Diagram 26

the box on a wooden holder. You will notice bending of the rays of light as they refract through the lens. Diagram 26 *b* shows the path of light through a diverging lens.

CONVERGING LENS

Whichever of the three types of converging lens you take, it can be recognised by the feel of hand; it is thick in the middle and becomes thinner at the edges. The property of a converging lens is to bend inwards (converge) light rays as they pass through the lens. If placed inside the smoke box, the converging lens will bring several parallel rays to one point after refraction (diagram 27 *a*). This action can be understood if we imagine a converging lens to be made up of several sections of triangular prism, with a thin glass slab in the middle (diagram 27 *b*).



(*a*) (*b*)

Diagram 27

If several parallel rays are incident on the lens, the ray AB will pass through straight without deviation or displacement, as it is incident normally and the two refracting surfaces are parallel to each other. The rays *C* and *D*, equi-distant from *AB*, while passing through the prism sections, deviate equally towards their bases, and therefore intersect at a point *F* on *AB*. As the converging lens gradually becomes thinner at the edges, refracting surfaces of the prism sections make greater angle between themselves. Therefore, parallel rays away from *AB* deviate more than those closer. In effect, all emergent rays pass through the point F.

SOME DEFINITIONS

The line *AB* is called the ***Principal Axis*** of the lens. Rays parallel to *AB* and incident on the converging lens, pass through a point *F* on *AB* after refraction; the the point *F* is called the ***Principal Focus*** (or simply ***Focus***) of the convergent lens. A point *O* inside the lens on the principal axis is taken to measure all distances from the lens. Any ray of light incident in the direction of this point (diagram 28 *a*) would pass through the point without deviation (because the two refracting surfaces are parallel), and with little displacement (because the lens is considered

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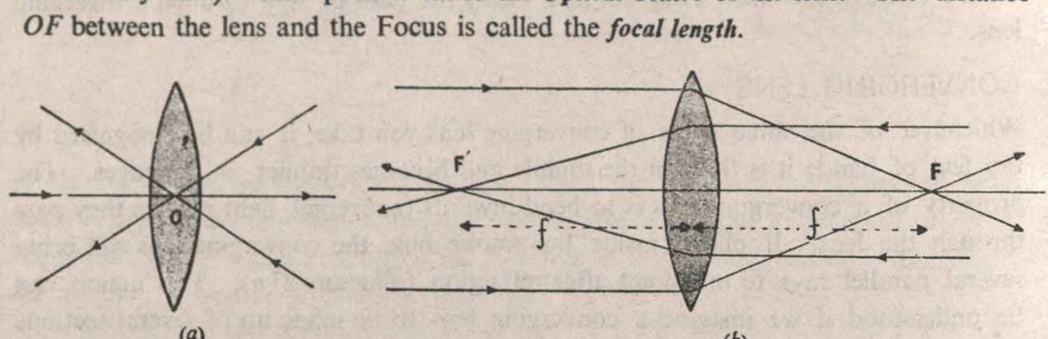
to be very thin). This point is called the ***Optical Centre*** of the lens. The distance *OF* between the lens and the Focus is called the ***focal length.***



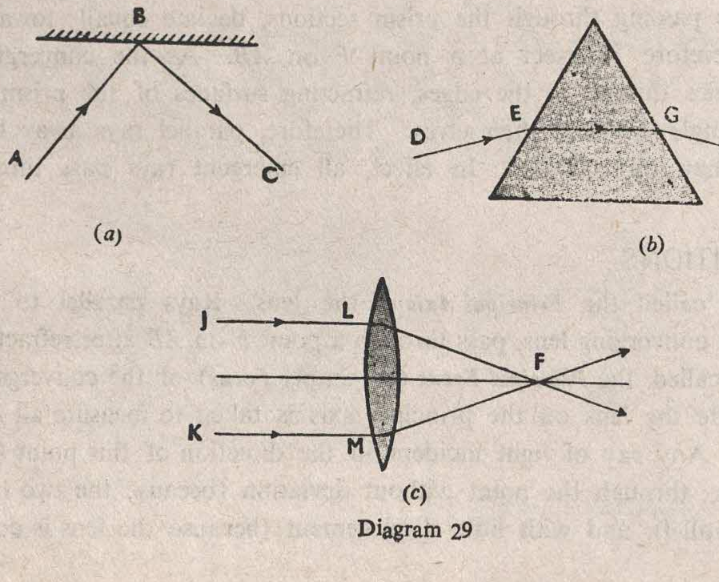
(a) (b)

Diagram 28

Light could be incident on a lens on either surface, but the property of convergence does not alter. Parallel rays incident on the left, will pass through focus *F* on the right side; if a parallel beam of light is incident on the right face, the emergent rays will pass through a focus *F′* on the left side (diagram 28 *b*). A lens therefore has a principal focus on either side; the focal length *f* is the same whether the distance is measured from one focus or the other.

REVERSIBILITY OF LIGHT

Consider a ray of light *AB* incident on a plane mirror and reflected in the direction *C* (diagram 29 *a*). If the ray is incident from *C* to *B*, the reflected ray will now be *BA* according to laws of reflection. Thus, reversing the path of light requires no change in the diagram except reversing arrow heads.



(a) (b)

(c)

Diagram 29

In diagram 29 *b*, the incident ray *DE* refracts through a prism and emerges as a ray *GH*. What would happen if the path is reversed and *HG* becomes the incident ray? The refracted ray will then become *GE* and the emergent ray will be *ED*.

Similarly, *JL* and *KM* are rays incident on a lens in diagram 29 *c*, and pass through *F* after refraction. If *FM* and *FL* are considered as incident rays, the bending due to refraction will be the same as before; *LJ* and *MK* will now be the emergent rays.

A PARALLEL BEAM

The reversibility of light is a useful principle which can be applied to determine the formulation of ray diagrams. Consider a point source of light placed at the focus of a lens on its principal axis (diagram 30 *a*). The source sends rays of light in all directions, and some of them are incident on the lens. The reversibility of light suggests that all rays coming from the focus and incident on the lens will go parallel to the principal axis.

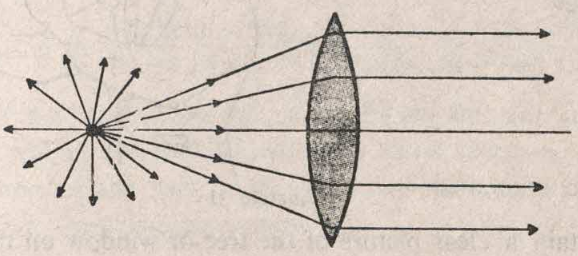


Diagram 30 (a)

Activity 2. Place a white sheet of paper facing the sun. Now hold a converging lens (magnifying glass) in the path of light, and adjust its distance, to obtain a bright spot on the sheet (diagram 30 *b*). Measure distance from the lens to the sheet.

Usually rays coming from a very distant object, such as the sun, are considered parallel to each other. The bright spot formed is therefore at the focus of lens; the distance from this spot to the lens gives us the approximate focal length of the lens.

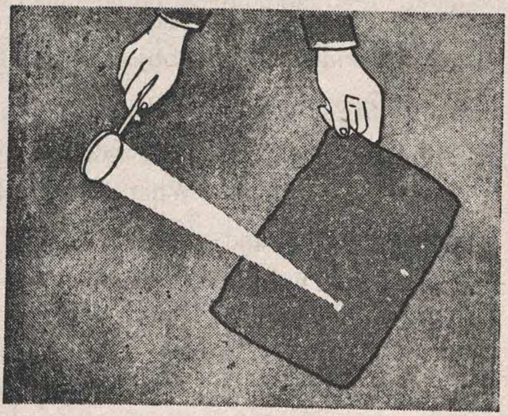


Diagram 30 (*b*)

IMAGE OF A DISTANT OBJECT

Activity 3. Stand inside a room and arrange the white sheet to face a distant bright object such as a tree or a window. Hold the lens in between at roughly the focal length distance. Adjust the lens and observe what you see on the sheet (diagram 31).

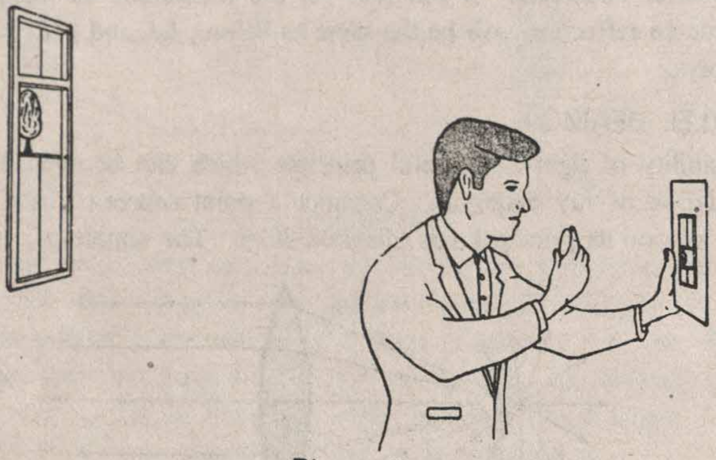


Diagram 31

You will obtain a clear picture of the tree or window on the sheet. This is an image of the object. Is it real or virtual? As in the case of the pinhole camera, the image has been taken on a screen; the image has been formed by rays actually incident on the sheet. Also the image is inverted. Thus, a real image is always inverted.

Measure the lens to image distance. You will realise that this distance is almost equal to (perhaps slightly more than) the focal length of the lens. For all practical purposes, therefore, we assume that rays incident on the lens from an object a few metres or more away are very nearly parallel; hence, the focus and image coincide when the object is very far away.

MAGNIFICATION

In the last experiment, you will have noticed that the image formed of the tree or window is very small. What decides whether the image is large or small?

Activity 4. Stand a lighted candle about 60 cm away from a white opaque screen. Now hold a lens between the two, close to the candle. (A lens of about 13 cm focal length is most suitable). Move the lens gradually away from the candle till you get a clear inverted image on the screen (diagram 32). Measure the distance of candle from lens u and of screen from lens v. Also measure the height of candle flame and its image.

Now move the lens away from the candle; at first the image becomes blurred and only a patch of light is seen on the screen. Continue to move the lens gradually towards the screen; there will be a second position of the lens when a clear image is formed on the screen. What is the size of this image? Measure and record the new distances of candle and screen from the lens. The ratio of image to object size is called ***magnification.*** Observations will show that

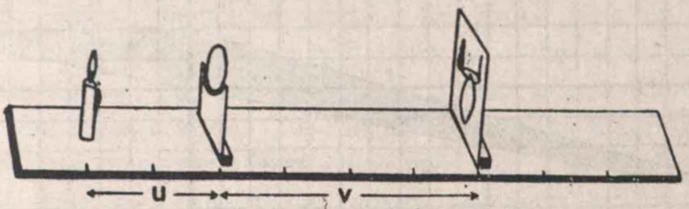


Diagram 32

$$\text{Magnification} = \frac{\text{height of image}}{\text{height of object}} = \frac{\text{distance of image from lens}}{\text{distance of object from lens}}$$

Thus, in the first position of the lens, if v is 40 cm and u is 20 cm, the magnification is 2. You will notice that the image is about twice as tall as the object. In the second position of the lens, both the image distance and its size are less than the corresponding object measurements.

GRAPHICAL CONSTRUCTION

On the basis of careful scale drawing, it is possible to determine the magnification and calculate focal length of the lens. The various steps for construction of a graphical ray diagram 33 are as follows:

(*a*) Draw a straight line *AB* in the middle of a graph paper to represent the principal axis.

(*b*) Select a convenient scale to show distances along the axis. For example, when the total candle to screen distance is 60 cm, a good scale may be 1 cm on graph=4 cm of actual measurement.

(*c*) Mark lens by a vertical line cutting the axis at optical centre *O*. The lens is so thin compared to other distances that it is shown as a thin straight line.

(*d*) Show the candle flame above axis *AB* by a vertical arrow *PQ* 5 cm from *O* on one side of the lens. It is not necessary that the scale chosen for vertical distances should be the same as for distances along *AB*. For example, in the present case, take the vertical scale as 1 cm on graph= 2 cm of actual distances. Then, if the object height is 2 cm, the vertical distance taken on graph is 1 cm.

(*e*) Draw a vertical line at S, 10 cm from O, to represent the screen 40 cm away.

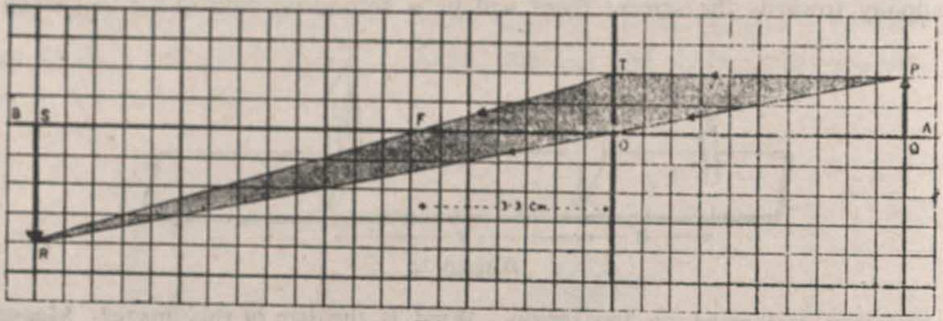


Diagram 32

(*f*) Take a ray PO from the top point on the object; this passes straight through the lens and meets the screen at R. The point Q will have a corresponding image point at S. RS is therefore the image of PQ.

(*g*) Since R is the image of P, any other ray from P incident on the lens will emerge and go straight to R. The most convenient ray is PT which is parallel to AB. Join T to R; the line cuts the axis at F.

A ray parallel to the axis, after refraction, passes through the focus; therefore, F is the focus of the lens. Measure FO. This distance is about 3.3 cm which gives the focal length of the lens $= 3.3 \times 4 = 13.2$ cm.

The distance RS is 2 cm, which gives the image height $= 4$ cm.

Thus, the image formed would be twice as large, real and inverted.

POWER OF A LENS

Focal length is an important physical characteristic of a lens. However, opticians usually talk about the ***power*** of a lens. Power is defined as the degree of convergence or divergence of a lens and is measured in ***dioptres.*** Power and focal length are related in a simple way. When the focal length is expressed in cm, and the power in dioptre:

$$\text{Power} = \frac{100}{\text{focal length}}$$

Thus, in the above experiment, when focal length of the lens is 13.2 cm,

$$\text{Power} = \frac{100}{13.2} = +7.5\text{ D}$$

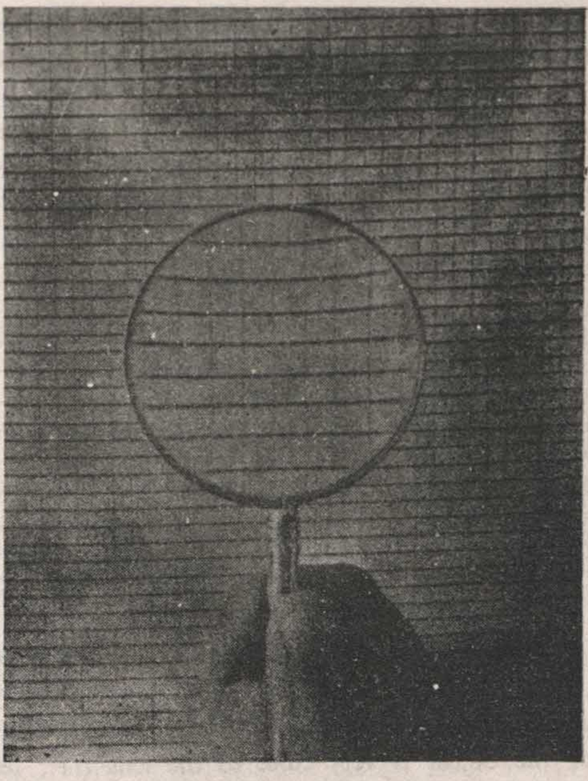
If the power of a lens is given as $+0.5$ D, we can find out its focal length by re-writing the above equation:

$$\text{focal length} = \frac{100}{\text{Power}} = \frac{100}{0.5} = 200\text{ cm}$$

If power of a lens is given as —0.5 D, its focal length will be —200 cm. The negative sign indicates that it is a diverging lens. A diverging lens has a negative power and a negative focal length.

Activity 5. Place a magnifying glass on this book. Now lift it and gradually move away from the book. You will notice that the letters appear enlarged. What you see through the lens is an image of the letters. Hold the lens on a graph paper and adjust it again. The squares appear to be bigger (photograph 34). Can you tell how many times is the image magnified? You will observe that the magnification increases as the lens is moved away from the graph paper, but the image gets blurred and distorted.

Although glass is the most common material used for lenses, other transparent materials are also used to magnify objects.



Magnification by a converging lens

Diagram 34

In this experiment, the image formed is upright and enlarged. An upright image, as in a plane mirror, suggests that it is virtual. Let us construct a ray diagram when the lens of a focal length 13.2 cm is held 6 cm away from the object. Proceed as follows:

(*a*) Draw axis *AB* and *LO* on a graph paper.

(*b*) Select a suitable horizontal scale, say 1:2. Hence, mark focus positions *F* and *F*′, each 6.6 cm from *O*.

(*c*) Take a 2 cm tall object *PQ* 6 cm away from lens; show it according to scale vertical on the axis.

(*d*) From *P* the rays of light shoot out in all directions. The three convenient rays to take and would be (*i*) *PO*, which is trasmitted undeviated, (*ii*) *PT*, is parallel to the axis, and passes through *F* after refraction, and (*iii*) *PM*, which comes from the direction of *F*, refracts and goes parallel to the axis. Actually any two of the three rays will serve the purpose of locating the image.

All the rays incident on the lens, including the three drawn (diagram 35) emerge after refraction as diverging rays. Since they cannot converge to a point, no real image is formed.

(*e*) Produce the three emergent rays backward; they intersect at a point *R*, which is the image of *P*. When you look through the lens, the point *P* appears to be at *R*. Similarly *Q* will have its image at *S*; hence, *RS* forms the image of *PQ*.

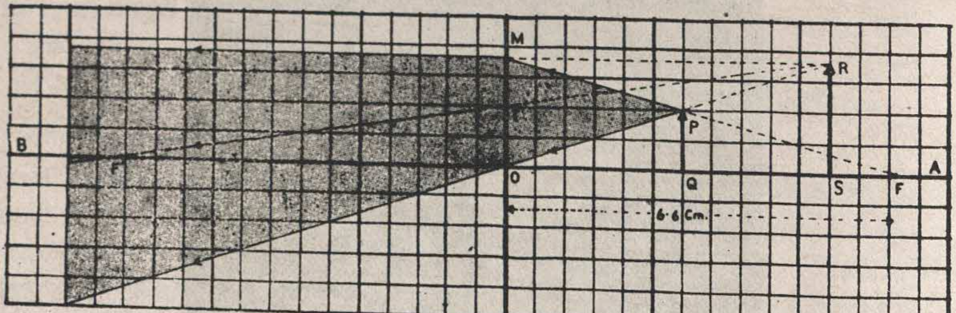


Diagram 35

(*f*) Measure *RS* and hence calculate the size of image and magnification achieved by the lens.

It may be noticed that a converging lens forms a magnified image under two conditions. When the object is very close to the lens (*i.e.*, less than the focal length distance), the image formed is virtual and upright. When the object distance is more than the focal length (but not very large), a real and inverted image is formed. An object far away, however, forms a small image. In fact, graphical construction and actual experiment will show that when the object is at twice focal length distance, its image is real, inverted and of the same size. The formula for magnification applies in all cases.

A divergent lens only forms a small and virtual image; its applications therefore are limited.

PROBLEMS

1. What are the main differences between a diverging and a converging lens (a) in their construction, (b) in their properties? Illustrate your answer with diagrams.
2. Explain the terms focus, principal axis and optical centre as applied to a converging lens. Describe one method of determining the focal length of this lens.
3. What is the difference between a real and a virtual image?
   With the help of clear diagrams, explain how a converging lens can produce an image of approximately twice the size of an object in two different positions of the object. What are the differences between these two images?
4. What is meant by power of a lens? Define a dioptre.
   Focal length of a converging lens is 30 cm. Calculate its power. What would be the focal length of a lens whose power is —4 D? What type of lens is it?
5. An object 5 cm tall is placed at a distance of 40 cm from a converging lens of focal length 16 cm. By graphical construction find out the position, size and nature of the image. Also calculate the magnification of the image.
6. A magnifying lens of focal length 20 cm is held 10 cm away from an object 0.5 cm long. By graphical construction find out the nature, size and position of the image.
   If the lens is moved nearer the object, will the magnification increase or decrease?
7. A parallel beam of light is incident on a wall in a room. A converging lens is held in its path close to the wall. A ***bright circular patch*** of light surrounded by a ***dark ring*** is formed on the wall. Explain with the help of a diagram the appearance of the two formed sections. If the lens is moved slowly away from the wall, how will the sizes of the bright patch and the dark ring be affected?
   What sort of appearance on the wall will you obtain if the converging lens is replaced by a divergent lens?

4

Optical Instruments

You have already studied one optical instrument, the periscope, which employs two plane mirrors. Telescope, microscope, projector and camera are examples of instruments which use lenses. You must have handled or seen at least some of these. They are our sense-extenders. Spectacles have lenses fixed to them. In fact, an eye is also an optical instrument with a lens.

LENS CAMERA

The box camera is similar in construction to a pin hole camera, except that there is a converging lens instead of the hole and the screen is a light-sensitive film. When the shutter *S* is open, light from a distant object passes through the lens and forms an inverted and diminished image on the film *E* (diagram 36). As long as the object is beyond about 4 metres, the image-lens distance is almost constant, which is slightly more than the focal length of the lens. When the camera is so adjusted, with the object not too close to the camera, the image formed on the film is reasonably sharp. The large lens surface allows plenty of light to enter the box thus forming a bright image; it also enables to adjust the time of exposure to a fraction of a second so that a sharp image of even a moving object can be formed.

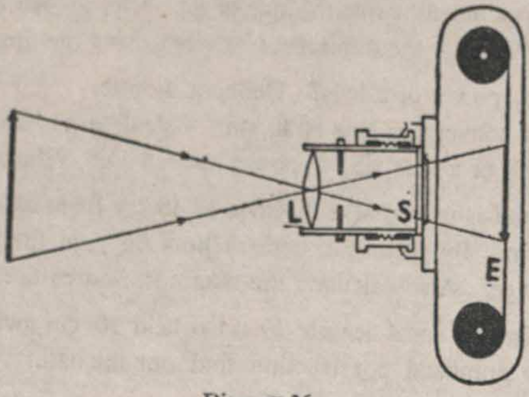


Diagram 36

In good cameras an ***aperture*** arrangement (opening of lens surface) and the timing device (shutter speed) together enable a controlled amount of light to fall on the film. The film thus exposed to light is then processed and a print of the image obtained. In such cameras, when the object is closer, the image-lens distance can be increased; this is achieved by moving the lens away from the film, employing a screwing arrangement.

SLIDE PROJECTOR

A slide projector (projection lantern) is used to cast a highly enlarged image of a slide on a far off screen. Essentially, it consists of two parts: (*a*) an arrangement to evenly and brightly illuminate the slide; and (*b*) a movable lens to project a real, inverted and enlarged image of the slide on a screen *S*.

A powerful electric bulb *B* produces the light which a lens *C* converges on the slide. This converging lens, called the ***condenser*** is a combination of two ***planc-convex*** lenses arranged in a special way to avoid dispersion of light; otherwise, the image is likely to become coloured near the edges. A ***concave mirror*** is at the back of the bulb so that light going in the other direction is reflected back.

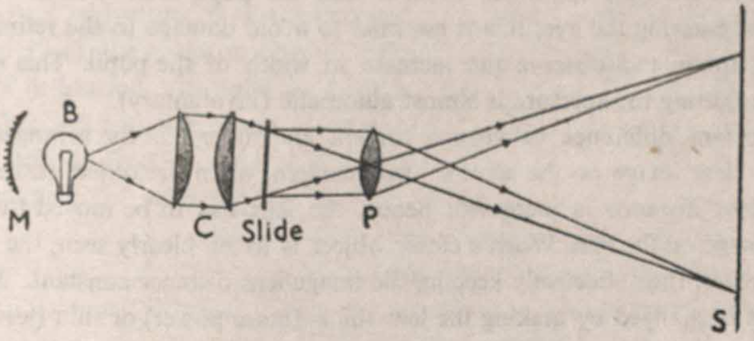


Diagram 37

In order to obtain a very enlarged image on a far off screen, the ***projection lens*** *P* must be very close to the slide, at a distance just more than the focal length of the projection lens. A small movement of the lens is necessary to obtain a clear image on the screen.

A cinema (movie) projector has almost a similar optical arrangement. However, the film can be run continuously and there is an additional sound system.

THE HUMAN EYE

The eye resembles a lens camera in many ways but there are some important differences also. In its action and performance, the eye is a very perfect and an automatic optical instrument.

The lens is made of a jelly-like material; it converges light to form a real, inverted and diminished image of an object on the light-sensitive screen called ***retina*** (diagram 38). The ***optic nerve*** carries the impressions on the retina to the brain where it is made erect and interpreted.

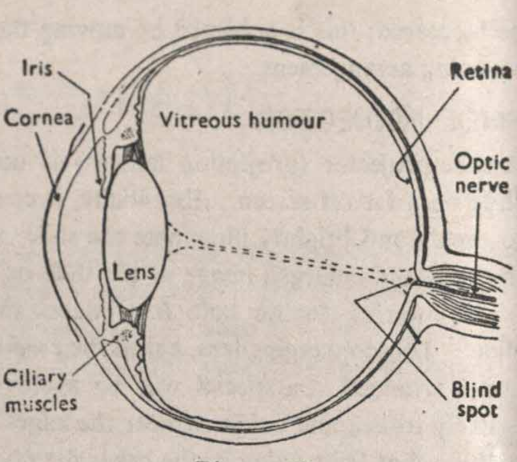


Diagram 38

The coloured circular portion in front of the eye lens is called the ***iris;*** by muscular action it adjusts aperture, thus controlling the amount of light entering the eye. The central opening through which light enters the eye is called ***pupil***; from outside, it appears black.

Activity 1. Hold a mirror in front of you and look into your eyes. Locate the iris and the pupil in the middle of it. Now shine a torch on one of the eye balls and notice how the pupil width changes. You will observe that the pupil area becomes less and controls light entering the eye; this is essential to avoid damage to the retina. Now remove the torch and observe the increase in width of the pupil. This action of the iris in adjusting the aperture is almost automatic (involuntary).

An important difference between a camera and an eye is the arrangement for obtaining a clear image on the screen. In a camera, when the object comes closer, the image-lens distance is increased; hence, the lens has to be moved forward to bring the image on the film. When a closer object is to be clearly seen, the eye lens power increases, thus effectively keeping the image-lens distance constant. Power of the eye lens is changed by making the lens thick (more power) or thin (less power); this is accomplished by stretching or relaxing the ***celiary muscles.*** This involuntary action of the celiary muscles, which is called ***accommodation of the eye***, suitably alters the power of the eye lens to obtain a sharp image on the retina when the object distance is changed.

When a very far off object such as the moon and stars is viewed, the retina-lens distance is equal to the focal length of the lens. In this condition the eye is most relaxed and the lens has least power. A closer object would require more power of the lens, increasing strain on the eye. The closest distance that any object can be held to be seen clearly is called the ***near point*** of the eye. In this condition the power of eye lens is maximum.

Activity 2. Hold this book in front of you and look at the words. Move the book closer to your eyes; keep your eyes fixed on the words. You will find that the words look blurred. Now gradually take the book away from your eyes and stop when you see the words clearly again. Measure the distance of the book from the eyes; this is the near point distance for your eye. For normal eye sight, the near point distance is about 20 to 25 cm; children have a closer near point.

DEFECTS OF VISION

We see lots of people around us wearing spectacles; some wear coloured glasses, whereas others wear them to correct defects of vision. Let us consider the cause of some defects and how spectacle lenses are used to correct them.

Myopia or Short Sight is a defect of the eye when a distant object cannot be seen clearly; this is caused when the eye ball is elongated so that the retina-lens distance is increased. For the normal eye, an object at great distance forms a clear image on the retina when the eye lens has least power (diagram 39 *a*). The same object will form a sharp image between the eye lens and retina in a myopic eye (diagram 39 *b*); the image on the retina will therefore be blurred. In order to correct such a defect, a negative power (diverging lens) is held in front of the eye; in effect, the convergence of incoming rays of light is less due to the spectacle and eye lens combination. Thus by using a suitable divergent lens in front of the eye, the final image can be brought on the retina (diagram 39 *c*).

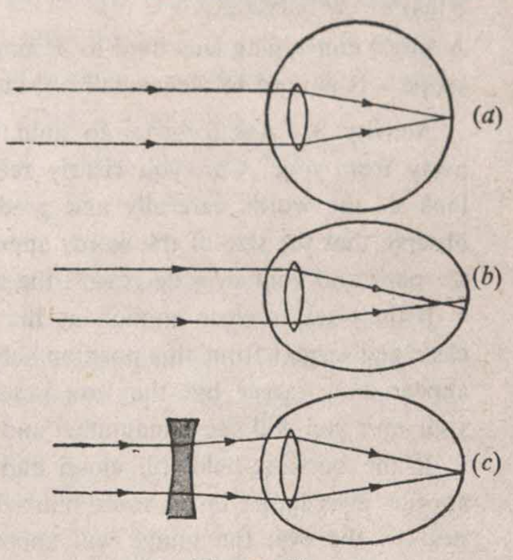


Diagram 39

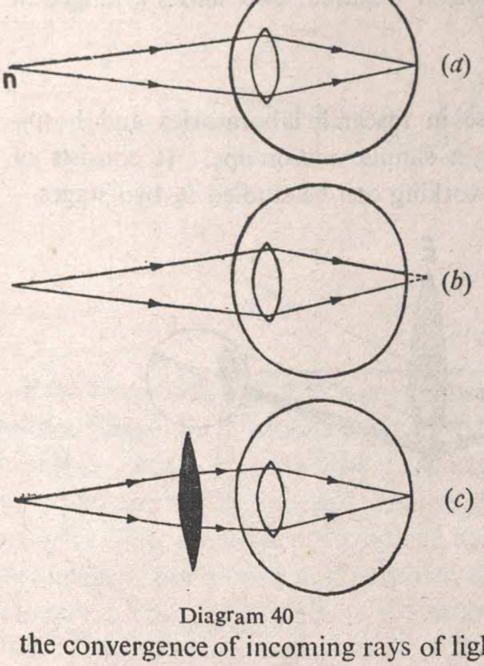


Diagram 40

Hypermetropia or Long Sight is a defect of the eye when near objects cannot be seen clearly; it is caused by shortening of the eye ball so that the retina-lens distance becomes smaller. For the normal eye, an object at near point ***n***, forms a clear image on the retina when the eye lens has maximum power (diagram 40 *a*). The same object will form a blurred image on the retina in a hypermetropic eye, because rays from the object would converge to a point behind the retina (diagram 40 *b*). In order to correct such a defect, a convergent lens is held in front of the eye lens; in effect, the convergence of incoming rays of light is more due to the combination of spectacle and eye lenses. Thus, using a suitable converging lens in front of the eye, the final image can be brought on the retina (diagram 40 *c*).

SIMPLE MICROSCOPE

A single converging lens used as a magnifying glass is also called a simple microscope. It is used to view small objects in greater detail.

Activity 3. Ask someone to hold this book at a distance of about 3 metres away from you. Can you clearly read the printed words on the pages ? Now look at the words carefully and gradually move closer to the book. You will observe that the size of the words appears to grow larger as the distance between the page and your eyes decreases; the actual size is however always constant.

If the book is close enough at the near point of your eyes, the writing appears clear and largest from this position. Now bring the book even closer; words may appear even larger but they are indistinct. Interpose a converging lens next to your eye; you will see a magnified and clear image.

If the book is held still closer and viewed through the unaided eye, the writing appears even larger but is more blurred. Now bring a high power converging lens next to the eye; the image will appear to be clearer and larger than if a weak converging lens is used. Thus, a lens of smaller focal length has greater ***magnifying power***. However, a small focal length lens is necessarily thick and produces distortion and colouring of the image near the edges. In good instruments where greater magnification without distortion and dispersion is required, two lenses arranged in a special way are used.

COMPOUND MICROSCOPE

The compound microscope finds extensive use in research laboratories and hospitals, and is a more advanced instrument than a simple microscope. It consists of two converging lenses (diagram 41), and its working can be studied in two stages.

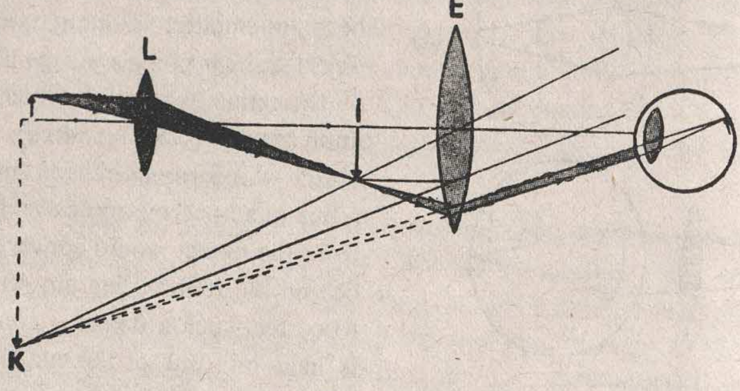


Diagram 41

The lens *L* placed very close to the small object is called the ***objective***. This lens forms a real, inverted and magnified image; the magnification will obviously depend upon the ratio of image-to-object distance. If these rays converging at the image position *I* are allowed to proceed to lens *E*, called the ***eye piece***, they will diverge after refraction and appear to come from *K*. When the eye is placed at the position shown in diagram, rays from object make the image *I* a secondary source of light whose magnified and virtual image is formed at *K*. Thus, magnification is achieved in two stages.

ASTRONOMICAL TELESCOPE

The purpose of any telescope is to make distant objects appear closer; this enables them to be seen clearly in greater detail. Telescopes employ lenses of both types as well as mirrors. Diagram 42 shows a method to obtain a magnified view of a distant object using two converging lenses: an objective of large focal length and an eye piece of short focal length.

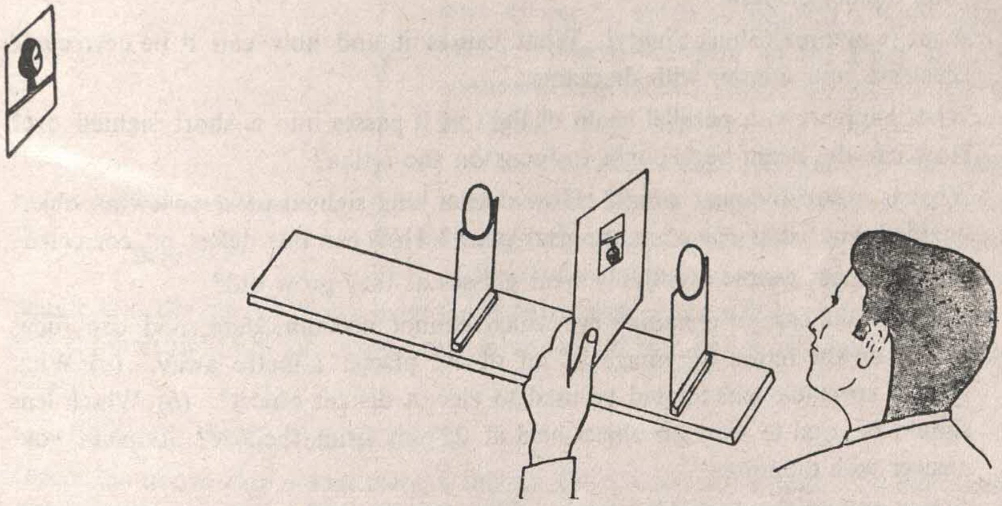


Diagram 42

Rays from a distant object pass through the objective to form a small, real and inverted image on a translucent screen. This image can then be seen magnified through a second lens; the final image as seen through the eye piece would be enlarged, virtual and remain inverted. If the translucent screen is removed away, the rays emerging from the objective continue their path to meet the eye piece and form the final image. For all practical purposes, therefore, the first image acts as an object to the second lens. The screen is not actually used in any telescope, but helps to set up a model telescope and understand the function of the two lenses.

It should be noted that the telescope and the microscope form an inverted and virtual image. With these instruments, therefore, the images cannot be taken on a screen; other arrangements are required to photograph images. With these powerful instruments it has been possible to extend greatly our knowledge of as small objects as living organisms and as distant objects as stars and galaxies.

PROBLEMS

1. Draw a simple and labelled diagram of the human eye. Compare the action of the human eye to that of a lens camera with regard to (*a*) the method of "focussing" near and distant objects, (*b*) the method of controlling the amount of light which enters the instrument.
2. State two similarities between the camera and the human eye. What are the limitations of a box camera? Is there any near point of a box camera or a good quality camera?
3. What is myopia (Short Sight)? What causes it and how can it be corrected? Illustrate your answer with diagrams.
4. What happens to a parallel beam of light as it passes into a short sighted eye? How can the beam be brought to focus on the retina?
5. What is meant by near point? How does a long sighted person view an object unaided when it is placed at the near point? How can this defect be corrected?
6. Why do most people eventually wear glasses as they grow old?
7. Consider the case of a human eye which cannot accommodate, and can focus clearly on the retina the image of an object placed 1 metre away. (*a*) What type of spectacle lens should be used to view a distant object? (*b*) Which lens should be used to view an object held at 25 cm from the eye? Explain your answer with diagrams.
8. A box camera forms a clear image on the film when the object is 4 m away. How can any external aid help to obtain a clear image of the object held 2 m away from the camera lens? Draw a diagram to explain your answer.
9. Draw two separate diagrams to show how (*a*) a projection lens forms an image of a slide on a large screen; (*b*) the slide is uniformly and brightly illuminated.
10. Compare the advantage and disadvantage of using as a simple microscope two converging lenses, one of large and the other of small power, for the reading of small print.
11. What is the function of (*a*) the objective, (*b*) eye piece in an astronomical refracting telescope?

5 Effects of Electric Currents

An electric heater is meant to give heat radiation, but it also gives out light. You will probably have noticed that an electric lamp feels warm to the touch. How are these two appliances different in construction? What other effects does electricity produce when it flows through a circuit? We shall study these now.

THE ELECTRIC CURRENT

Activity 1. Connect a series circuit using three torch cells, a lamp, a 20 cm length of ***nichrome wire*** of "28 SWG" thickness, and a switch (diagram 43). A 'crocodile clip' *C* is used so that the contact on wire *AB* can be made as required. Now switch on and observe the glow in the lamp as *C* is connected and shifted from one end of *AB* to the other.

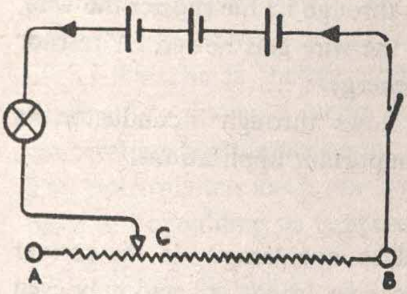


Diagram 43

You will notice that the glow in the bulb increases as a shorter length of wire *AB* is introduced in the circuit. The glow is an indication of the electric current through the circuit. We assume that the current flows from the positive pole of the cell towards the negative pole through the bulb and wires; this is shown in the circuit diagram by arrowheads.

RESISTANCE AND RESISTORS

Repeat the above experiment using a thinner (36 SWG) wire as *AB*. To make any useful comparison, you must take the same cells and the wires taken should be of same material (nichrome). You will observe that the glow now diminishes rapidly. The thin wire of a shorter length can affect the glow to the same extent as the thick wire of a greater length.

In the experiment, the wire *AB* is used to restrict or alter electric current through the bulb. Such wires are often used in electric circuits. *A conductor which alters or restricts the flow of electric current in a circuit is called a* ***resistor***.

We also observe that the thin wire restricts the current more than a thick wire of the same length and material. The thin wire is therefore said to have more ***resistance***. As the length of a wire increases, its resistance also increases.

In the above circuit, the wire *AB* is used as a resistor. Earlier we have noticed that if an additional bulb is introduced in a series circuit, the glow in the bulbs becomes less. Thus, a bulb is also a resistor. Examine a bulb and you will realise that it is the filament in it which is responsible for increase of resistance in the circuit.

Resistors are used in large quantities in electronic circuits. Some resistors are variable, such as the "volume control" of a receiver; such variable resistors are called ***rheostats***.

THE HEATING EFFECT

What does a resistance do besides restrict the current through a circuit?

Activity 2. Connect the circuit again employing three cells and the wire *AB*. Connect clip *C* to *AB* near the end *A* and observe if the wire feels warm. Now move the contact *C* near the end *B* and feel the wire again.

You find that the wire gets warm as current flows through it; the shorter the wire, more would be the current through the circuit, and the wire gets hotter. A resistor is therefore a convertor of electrical energy to heat energy.

As a matter of fact, whenever electric current flows through a conductor, its temperature rises. We can now discuss one of its important applications.

THE FUSE

What would happen if several cells are connected to one lamp? If the current increases too much, the filament of the bulb will become bright hot and may even blow up.

Activity 3. Take a thin strand about 4 cm in length from a pad of steel wool and connect it by crocodile clips to three cells in series. Blow gently over the steel strand. You will notice that the wire becomes red hot, burns off and breaks the circuit.

In the domestic electric supply, there is alway the odd chance that a faulty connection might suddenly increase the current in circuits and damage electrical wiring; this will then become a fire risk. To avoid this risk, a wire of low melting point material is included in the circuit; when the current exceeds a certain limit, the wire becomes warm and quickly melts, thus breaking the circuit. Such a special wire, usually a lead alloy of low melting point, included in an electric circuit as a safety device is called a ***fuse***.

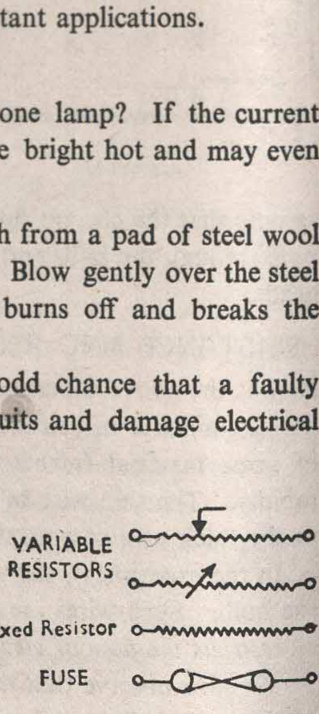


Diagram 44

TEMPERATURE AND RADIATION

We have seen that three ways in which the resistance of a conductor can be altere are: change of length, thickness and material. The filament of a bulb and the element of a heater differ in all these three respects.

If the two have the same resistance and the electric current passing them is also the same both will convert electrical energy to the same extent; however, the construction being different, one will give more light while the other will give more heat radiation.

The heater element is made of nichrome; the wire is thick, long and well exposed to air. When electrical energy is converted to heat energy, the greater surface, and contact with air, enables it to dissipate heat quickly by convection and radiation to surrounding air. Its temperature therefore does not rise very high; the reddish-yellow glow of the element shows that its temperature is between 800 and 1400°C.

The filament of a bulb (which works on the mains supply) has a short and thin filament which is so coiled that the surface exposed is very small. Moreover, the filament is enclosed in a glass bulb which contains very little gas. Thus, heat losses due to convection and radiation are minimised considerably. The temperature of the filament is therefore very high, in the region of 2500 to 2700°C. This enables it to dissipate energy largely in the form of light. To withstand this high temperature, the filament is made of ***tungsten***, whose melting point is about 3500°C. The near-vacuum inside the bulb does not allow oxidation of the filament to take place, thus enabling its temperature to be raised very high.

MAGNETIC EFFECT

Activity 4. Place a compass needle on the table. Hold a long copper wire of 28 SWG between your hands in the north-south direction on top of the needle, and connect its two ends to a cell (diagram 45). You will notice a deflection of the compass. Now hold the wire below the needle; the deflection will be seen in the other direction.

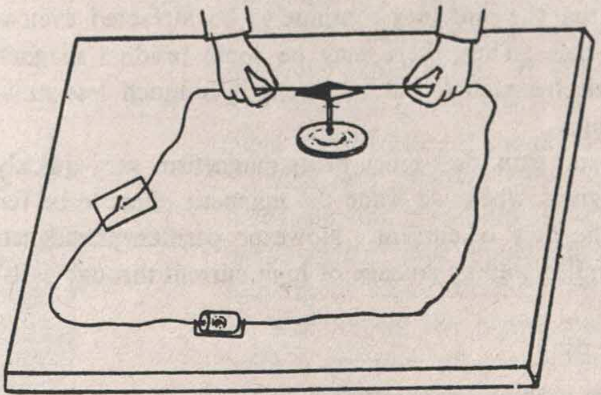


Diagram 45

It appears that when a current flows in a wire, it creates a magnetic field around it which causes the magnetic compass to be deflected. This is known as the magnetic effect of an electric current. What would happen if more cells are used in series?

The fact that the deflection increases with increase of current finds practical application in the detection and comparison of electric current by galvanometers.

SOLENOID AND ELECTROMAGNET

Activity 5. Now make the wire into a coil by wrapping it round a pencil. Pass current through it and bring the compass needle near it, first to one end then to the other. Note the deflection; these will be in opposite directions.

Now put 3 or 4 small iron nails into the coil so that the coil is wrapped round the nails. Bring the compass needle near it and again note the deflections. You will observe that the deflections are more now. Bring other nails near it; these will be attracted to the nails inside, and may even get attached to them. Increase the current by including more cells in the circuit; the magnetic effect will also be enhanced.

Such a long coil which carries electric current and produces a magnetic effect is called a ***solenoid***. When nails are inserted through it, it behaves as an electromagnet. The electromagnet attracts iron and other magnetic pieces just like a bar magnet.

The magnetic field around an electromagnet is of a similar pattern to that of a permanent bar magnet. A simple rule to remember which end becomes the North-seeking pole, and which becomes the *S*-pole, is to view the end faces from the sides. If the current around the core is clockwise, the face is a *S*-pole.

Activity 6. Now pick some heavy objects with the electromagnet, *e.g.* a steel ball. Switch off the current. What do you notice? Bring some pins close to the coil; you will see that the pins may continue to be attracted even when no current flows through the coil. Thus, there may be some residual magnetism left in the iron ***core*** of the electromagnet, but its strength is much less now than when the current was passing.

As you know, soft iron loses much of its magnetism very quickly; it is therefore used in electromagnets when we want the magnetic effect to be temporary for the the duration of the flow of current. However, permanent magnets from steel are also made in a similar way by passage of high current through coils wrapped round them.

THE ELECTRIC BELL

Electromagnets are used in many devices such as relays, automatic cut-outs, etc. The electric bell is a simple and common practical application.

If you follow the diagram 46, you will notice that the bell essentially consists of an electromagnet which attracts a strip of iron when the switch completes the circuit. However, the strip must fall back and hit the gong repeatedly if the bell is to ring continuously; this requires that the strip is attracted and released alternately. When the circuit is complete and the strip, called the ***armature***, is pulled by the electromagnet, the contact with adjustable screw at *S* is broken; the electromagnet gets demagnetised and the armature returns to its original position due to the springiness (elasticity) in it. This remakes the contact at *S*, the circuit is completed and the armature is pulled again by the electromagnet. The process is repeated and the bell rings continuously while the switch is closed.

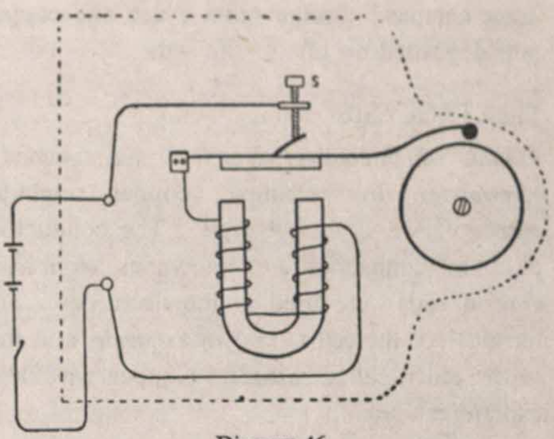


Diagram 46

CHEMICAL EFFECT

So far we have come across many examples of conductors and insulators of electricity; these were all solids. Do liquids also conduct electricity?

Activity 7. Take several liquids in beakers. Fix two pencil leads or carbon rods to three cells and a lamp and dip the two carbon rods into the liquids one by one (diagram 47). The carbon rods can be easily obtained from cells that have been used up in previous experiments. If the liquid conducts, the lamp will glow. Make a table and record your observation for the different liquids.

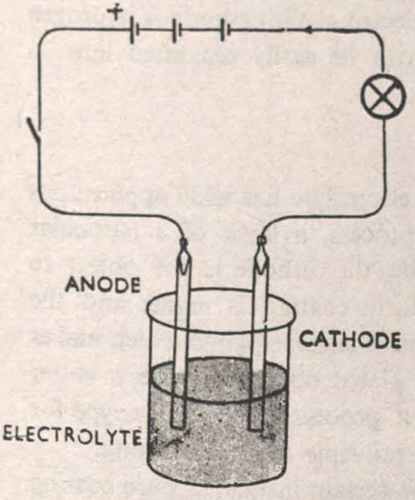


Diagram 47

You will discover that pure water and kerosene are insulators while dilute sulphuric acid, mercury and copper sulphate are some of the liquids which conduct electricity.

Now repeat the experiment more carefully with a solution of copper sulphate. Pass a current for about 5 minutes. Remove the rods and see if you notice any change.

You will notice that one rod appears pinkish as if copper has been deposited on it. If you test the rod on a Bunsen flame, it glows with a typical green flame of copper. Where has the copper come from? During the passage of electric current, some chemical change takes place and copper from the solution is released which gets deposited on one of the rods.

ELECTROLYSIS

Liquids which conduct electricity accompanied by a chemical change are known as ***electrolytes***. For example, copper sulphate solution is an electrolyte while mercury is a non-electrolyte. The conductors that dip into the liquid to make electrical connection are known as ***electrodes***. In the above experiment, the two carbon rods were used as the electrodes. The electrode connected to the positive terminal of the cell is known as ***anode***, and that connected to the negative terminal of the cell is called ***cathode***. Copper was deposited on the cathode in the above experiment.

Activity 8. Replace the carbon electrodes with nichrome, or preferably platinum wires. Bend the platinum wires into a hook so that they rest on the rim of a beaker filled with distilled water, with only the platinum electrodes dipped in water. Connect the circuit and you will notice that the lamp does not glow.

Now carefully add a few drops of sulphuric acid to the water; as seen earlier, the liquid begins to conduct. Note carefully if any chemical change is taking place inside the liquid. You will observe gas bubbles forming around both the electrodes. Collect the gas in a test tube; for this, the test tubes are first filled with the electrolyte, and then inverted and held over the electrodes. Test the gas with a glowing splinter. It will be found that the gas collected at the cathode is hydrogen while that at the anode is oxygen. Thus water can be easily separated into its components by electrolysis.

APPLICATIONS TO CHEMICAL INDUSTRY

Electrical separation by passage of current into an electrolyte has wide applications in the chemical industry. In the electro-plating process, a layer of a particular element is coated on another conductor. Generally, the cathode is the object to be electroplated, the anode is the metal of which the coating is made, and the electrolyte is a salt of the metal. For example, iron is chrome-plated which makes the surface rust-resistant. Silver, gold and nickel plated objects acquire a better appearance and harder surface. Electro-typing is a process by which the type for printing materials are made; this depends upon the principle of electroplating.

The electro-plating process is also used to refine certain metals; a pure coating on the cathode is obtained when the anode is impure. Gold, silver, zinc and tin are obtained in a refined form this way. Extraction of aluminium, sodium, etc. also depends upon the electrical method of separation.

PROBLEMS

1. Explain with the aid of a diagram the action of a fuse in an electrical circuit.
2. In which ways does the filament of a lamp differ from the element of an electric heater? How does the difference help in the function of these two appliances?
3. How can you show that a magnetic field exists around a coil carrying current? How can you detect the direction of the field? State two ways by which you can increase the strength of an electromagnet. Why is soft iron used in preference to steel as the core in the construction of an electric bell?
4. Explain with the aid of a clear diagram the working of an electric bell.
5. Draw a labelled diagram of the apparatus set up for the copper-plating of a brass nail. How can the current in the circuit be controlled? Mention three practical uses of electrolysis.

6 Experiments with Sound

Seeing is one of the best ways of finding out about things that go on around us; hearing is another. We feel thrilled listening to an exponent of music play on his sitar or sarod, but get irritated at the rattling of windows due to sonic booms or thunder of clouds. Loudspeakers and vehicles make us unpleasantly aware of sounds in cities. The chirping of birds and the gentle murmur of a stream are experienced on mountains and in forests. We hear with our ear the sounds produced by all these sources. How is sound produced? How does it reach our ears? What makes a sound unpleasant or melodious?

VIBRATIONS

Activity 1. Pluck the string of a musical instrument and watch how it moves. A paper rider placed on the string will jump off.

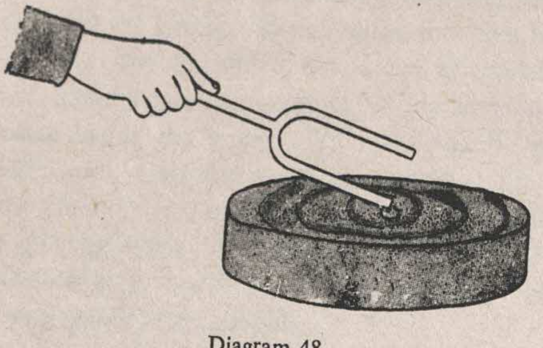


Diagram 48

Strike a ***tuning fork*** against a soft pad, such as a rubber bung or the rubber sole of a shoe. Observe closely the ***prongs*** of the tuning fork; they appear hazy. Feel them with your fingers.

Hold the tuning fork over water in a wide trough with one prong just touching the water surface (diagram 48). You will see ripples produced on the water surface spreading out from the point where you touch the prong.

Connect an electric bell in series with a switch and two cells. When you close the circuit, observe the hammer hitting the gong. Switch off and notice how the hammer movement dies out.

Sound is generated by the vibration of objects. Every sound that you hear can be traced back to some source that vibrates. Vibration is the name given to the ***to and fro movement*** of an object.

MEDIUM TO TRAVEL

The sound from a source reaches our ears through the air. What would happen if the air were absent?

Activity 2. Suspend an electric bell inside a bell jar, and take out the wires leading to it through a tight cork. Place it on a flat circular disc; the disc has a hole in the middle which is connected to an exhaust pump. Edges of the jar are greased so that its contact with the disc is air-tight (diagram 49). Now connect cells and a switch in series with the bell and complete the circuit. Notice the movement of the hammer and listen to the sound, as current passes through the bell.

Now gradually remove air from the bell-jar by means of the exhaust pump. You will observe that sound from the bell becomes weaker, and ultimately almost inaudible, but the hammer is seen to vibrate and strike the gong continuously. Now release air again into the bell-jar by disconnecting the pump; the sound is again heard clearly.

Activity 3. Place a watch under a pillow. When you sleep with one ear pressed against the pillow, you can distinctly hear the ticks. If you scratch one end of a wooden plank or rod, it can be clearly heard if an ear is pressed against it at the other end.

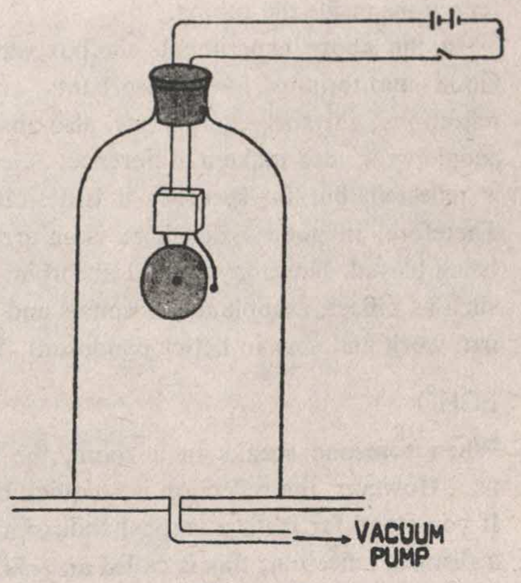


Diagram 49

Sound travels through air, liquids and solids. In the absence of any medium, no sound will be transmitted. These experiments also show that loudness is less when air is rarer, and when sound travels through a rare medium (air) in comparison to a dense medium (wood).

REFLECTION AND ABSORPTION

When sound travels in one medium and reaches the surface of another medium, it is either refracted, absorbed or reflected.

Activity 4. Take a box lined with cotton wool. Place a ticking clock into it. Stand slightly away from the box so that the ticking sound is not heard (diagram 50 *a*).

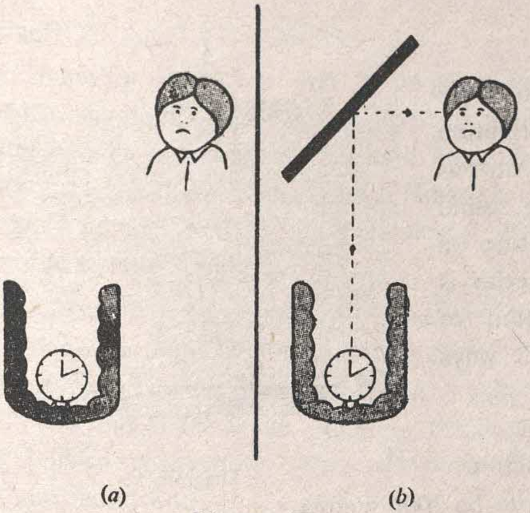


Diagram 50

Now hold a card sheet above the open end of the box. Gradually tilt the sheet till you hear the sound (diagram 50 *b*).

It is observed that sound is reflected just like light or heat radiations. You could construct a simple ***stethoscope*** using a rubber tubing and a glass funnel fitted at one end. Hold the funnel on a clock and place the other end of the tubing into your ear. You will hear the ticking sound which reaches you after many reflections inside the tubing.

In the above experiment, the box was lined with cotton wool to absorb sound. Good auditoriums have absorbants on the wall at the back to stop undue reflections; curtains, carpets, etc. also absorb sound to a certain extent. Clothes that people wear also make a difference. Generally, musicians prefer that some sound is reflected, but for speeches it is desirable that the sound fades out very quickly. Therefore, in good halls there is an arrangement to remove materials if music is being played. Nowadays sound absorbing materials are used at a number of places, such as offices, aeroplanes, hospitals and factories, to cut down noise so that people can work and stay in better conditions. Too much of sound leads to nervous strain.

ECHO

When someone speaks in a room, the sound is reflected by all the walls around us. However, the reflection is so quick that it gets mixed with the original sound. If you stand far from a vertical wall or a cliff and utter a loud sound you can hear a distinct reflection; this is called an ***echo***.

Once the speed of sound in a medium is known, the echo can be useful in measuring distances of reflecting objects. The distance, speed and time are related in a simple way as given by the following equation:

$$\textbf{Speed} = \frac{\textbf{distance covered}}{\textbf{time taken}}$$

For example, the speed of sound in water is about 1500 metres/second. This information is used to find out the depth of seas at various places to chart the sea bed, by sending sound signals through water from ships floating on the water surface (diagram 51). If an echo is received 4 seconds after the production of sound, then the distance covered both ways by sound is given by:

$$\text{Distance both ways} = \text{speed} \times \text{time taken}$$
$$= 1500 \times 4 = 6000 \text{ metres.}$$

Depth of sea at that place would therefore be 3000 metres.

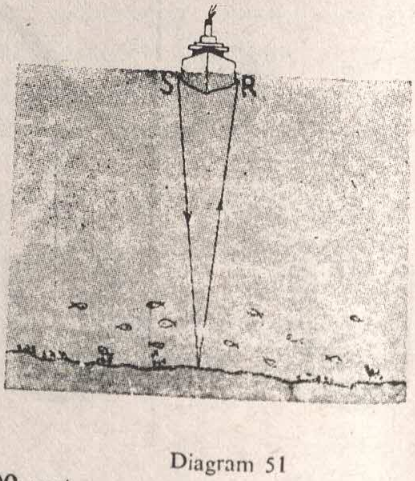


Diagram 51

SPEED OF SOUND

When a starter in an athletic event fires a gun, the sound is heard a fraction of a second after the smoke is seen from the finish line of a 100 m race. Spectators watching a game of cricket hear the sound a split second after a batsman makes a stroke. Obviously, sound travels fast enough but not as fast as light does. The echo method can be used to find out the speed of sound.

Activity 5. Stand about 100 metres away from a tall vertical wall of a building; it is necessary that there should be no other building close by to produce unwanted echoes. Clap your hands once; you will hear an echo after a split of a second. The time taken is so small that you cannot measure it accurately. The simple echo method therefore cannot be used to find out the speed of sound.

Now clap with a steady rhythm, ***periodically***, such that the echo arrives between two successive claps. Once the rate of clapping is adjusted with some practice, record the time for, say, 40 clap-intervals (time between 1st and 41st clap); you will need the help of someone else to record the time.

Let us assume that the time interval between 40 claps is 48 seconds.

Then, time interval between two successive claps $=\frac{48}{40}=1.2$ s.

In half this time sound goes to the wall and returns.

Therefore, time taken to travel 200 m $=0.6$ s.

$$\text{Hence, the speed of sound in air} = \frac{200 \text{ m}}{0.6 \text{ s}} = 333 \text{ metres/second}$$

Careful experiments show that the speed of sound in air increases with temperature and is about 340 m/s or 1650 km/h at normal temperature. Jet planes capable of exceeding this speed are called supersonic aircrafts.

ENERGY AND LOUDNESS

A sounding object has first to be given energy to make it vibrate. As the sound energy spreads around, mechanical energy in the source becomes less; its vibrations are seen to fade out. The sound heard from a tuning fork or a vibrating string becomes weak as time passes. However, an electric bell can receive continuous supply of energy from the cells; hence, its sound can be maintained by switching on the electric supply.

Activity 6. Firmly clamp a hacksaw blade (a stiff metal strip would do) on to a table with the help of a G-clamp; about 15 cm of the blade should project out of the edge of the table (diagram 52*a*). Allow the strip to vibrate by pressing down the free end of the blade. Observe the extent of the to and fro swing of the blade, and listen to the note. You will notice that the swing becomes less while the sound fades out.

The maximum distance from the rest (undisturbed) position through which a vibrating object moves is called its ***amplitude.*** The extent of vibration (amplitude) is a measure of the energy stored in the vibrating object.

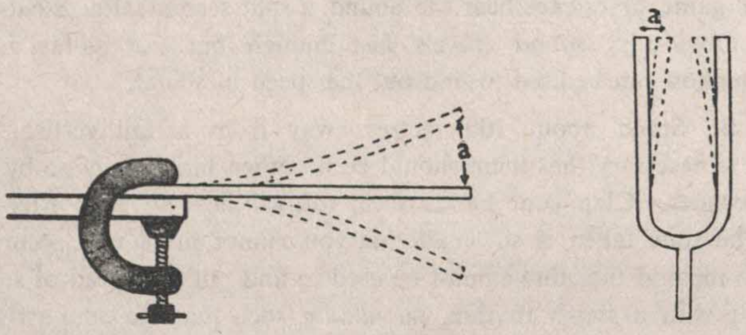


Diagram 52

A note on a piano can be made louder by striking it hard. Stronger vibrations of sounding objects produce greater energy; an object vibrating with less amplitude will also transmit less energy. Thus a tuning fork vibrating vigorously will show greater displacement of its prongs. The energy also depends upon how massive the object is; a light (less mass) object will contain less energy.

MECHANICAL WAVES

When vibrating objects lose their mechanical energy to the surroundings, it is carried away from the source in all directions. This transfer of energy takes place in the form of waves.

Activity 7. Drop a stone in still water in a pond; you will see circular waves spreading out on the water surface. Thus energy is ***propagated*** with equal speed in all directions on the surface of water. If there are any dry leaves (or a paper boat) floating on the surface, you will notice that they move ***up and down*** while energy is transferred along the surface; the floating objects themselves do not move in the direction of the wave.

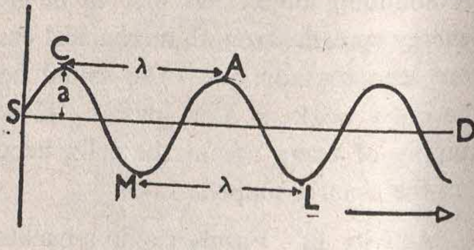


Diagram 53

Diagram 53 shows a section of the water surface; a vibrating source at S produces a wave which proceeds in the direction SD. The particles of water between source and D (for example C and M) move up and down, and themselves vibrate, as the wave proceeds along SD. *When particles of a medium vibrate perpendicular to the direction of wave motion, this is called* ***transverse wave motion.***

In the diagram, *a* denotes amplitude, the maximum distance of displacement of the particle *C*. As the wave proceeds along *SD* the amplitude of vibrating particles decreases due to gradual spreading and loss of energy in the form of heat. Similarly, the loudness of sound decreases with increase of distance from the source of sound.

SOUND PROPAGATION

The air carries sound energy in the form of waves. A vibrating loudspeaker S, for example, pushes air at regular intervals of time while its cone moves forward. When air in a particular region gets squeezed due to a push, we say that a ***compression*** is formed. The push is transmitted further away from the source along the compression.

However, as the loudspeaker cone is pulled back air in front of it gets spread out and a low pressure region is created; this is called a ***rarefaction.*** A second compression then follows, and so on. The air particles themselves only vibrate forward and backward as the energy is transmitted forward in the form of compressions and rarefactions (diagram 54). *When the particles of a medium vibrate in the same line, as the direction of propagation of a wave, this is called a* ***longitudinal wave motion.***

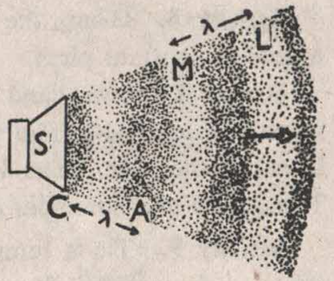


Diagram 54

Thus, sound is transmitted away from a source like ripples in air. However, instead of moving up and down (transverse) as in the case of water, air particles vibrate forward and backward (longitudinal). It should be noted that in both cases the particles of the medium do not themselves drift in the direction of wave propagation. Also, if the amplitude of vibration of source is greater, then the particles of the medium through which the energy is transmitted will vibrate with greater energy.

WAVELENGTH

When a compression *C* is produced by the loudspeaker cone (diagram 54), the previous compression will have travelled forward to *A*. Successive compressions proceed forward while the distance between any two adjacent compressions is constant, because the speed is constant. This distance is also equal to any two adjacent rarefactions, such as *ML*. This distance is covered by the wave during one complete to and fro movement of the cone. *The distance travelled by a wave in one complete vibration of an energy source is called its* ***wavelength,*** *and denoted by* λ.

In the case of a transverse wave, such as a wave on a water surface, the diagram 54 shows the distance *CA* or *ML* as equal to one wavelength.

PITCH

Many sounding objects vibrate at a constant rate; then they produce a steady ***note***. *The number of vibrations that a source of sound makes every second is its* ***frequency****; the frequency of any note is its rate of vibration.* A higher pitch increases shrillness of the sound produced. Thus, a tuning fork is often marked to indicate its constant pitch. If its pitch is 320 ***hertz***, it means that the prongs make to and fro vibrations 320 times every second. Any other sounding object, vibrating with a frequency of 320 hertz will appear to have the same tone. Musicians tune instruments to match the frequency by listening to the tone they produce.

Activity 8. Clamp the hacksaw blade again and make it vibrate. You will hear a note of constant pitch. Allow the sound to fade away; the pitch will not change.

Stretch a rubber band tightly between two supports. Pull it sideways with a finger and let it go. You will hear a note as it vibrates. Now pluck it harder and listen to the note. The loudness will be more but the pitch remains unchanged. Thus, *pitch of a note does not depend upon its loudness.*

Activity 9. Tie a lump of metal, such as a spherical *bob* or a 50 g mass, to a string, and suspend it from a retort stand. You now have set up a pendulum. Pull the bob to one side and release it; the pendulum makes to and fro movements. Each complete to and fro movement (diagram 55) is called an ***oscillation***. Time the pendulum for 10 oscillations; hence, calculate the ***time period T*** for one oscillation. Increase amplitude of oscillation and record the time period again. Take a heavier mass and repeat the experiment. You will observe that the time period does not change with change of mass of bob or amplitude.

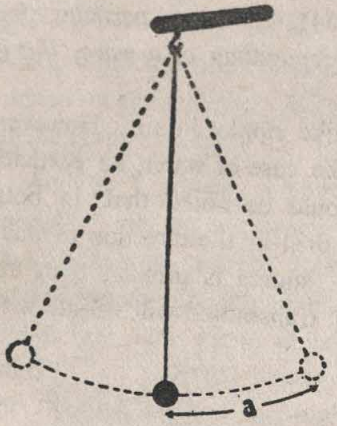


Diagram 55

Now change the length of the pendulum and repeat the experiment to calculate the time period for varying lengths of the pendulum. The experiment shows that the time period of a pendulum increases with increase of length of the pendulum. Pendulum clocks are based upon this principle to measure time.

Consider a vibrating object of frequency f whose energy propagates with a wavelength λ. In one vibration, the wave proceeds a distance λ. Hence in one second the wave proceeds a distance $f \times \lambda$ in the forward direction. The speed of this wave is therefore related to frequency and wavelength by the following equation:

$$\underset{\text{m/s}}{\text{Speed }(V)} = \underset{\text{Hz}}{\text{Frequency }(f)} \times \underset{\text{m}}{\text{Wavelength }(\lambda)}$$

For example, if a tuning fork produces a note of frequency 320 Hz, and the speed of sound in air is 340 m/s, the wave will proceed forward with a wavelength

$$=\frac{340\text{ m/s,}}{320\text{ Hz}}=1.06\text{ m}=106\text{ cm approximately.}$$

SIREN

Activity 10. An example of change of pitch with frequency is a siren. It consists of a rotating disc with a number of equally-spaced holes along a circle. Air is blown through a jet along the circle (diagram 56). As the disc rotates, air escapes through the holes when they come in front of the jet; when a hole is not in front of the jet, the air is blocked. Thus compressions and rarefactions are created in front of the jet.

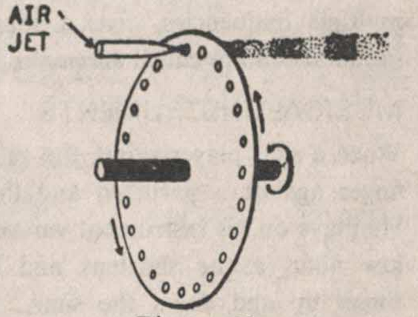


Diagram 56

When the disc is rotated at constant speed, a constant note is heard. With increase of speed of the disc, the rate of vibration of air increases and the pitch is raised. If the disc speed is not constant, a changing pitch will be heard; this is what happens when the air raid siren is heard.

SOUND OF NOISE

When sounding objects vibrate at many different rates and their pitch is constantly varying, they make noise. For example, when we bang our fist on a table, the sound we hear is not musical because the vibration rate is rapidly changing. *Noise is a jumble of varying notes without any simple relationship between them.* The instruments in an orchestra are tuned so that the notes produced together develop a pattern which is pleasing to the ear.

Human ears are sensitive to sounds with frequencies ranging between 20 and 20,000 Hz approximately. These limits are reduced with age and defects. Sounds which have frequencies above our audible limit are called ultrasonic sounds; those which have frequency below our audible limit are called infrasonic. For example, an oscillating pendulum produces waves in air just like any other vibrating object, but our ears cannot perceive any sound.

Bats are known to produce sounds of about 50,000 Hz; employing the principle of echo, they use this to locate prey, and avoid obstacles in their path, as they move. It is known that some fish communicate by ultrasonic sounds, and this knowledge is used in some places to produce ultrasonic sounds electronically, to attract fish and catch them in nets.

QUALITY

If a violin, a guitar and a piano are tuned to play the same tone, the strings vibrate with the same pitch. Yet, it is possible to identify instruments by listening to the sounds they produce. This difference in sound gives each instrument its distinctive quality. Studies show that most vibrating objects generate not just one pitch but several others which are multiples of the lowest pitch. The lowest note is called the *fundamental* and has most of the sound energy being transmitted. The small proportion of energy, and their distribution, among the multiple frequencies, gives a sound its quality. The multiple frequencies of the fundamental are called *harmonics or overtones*.

MUSICAL INSTRUMENTS

When a sitar player raises the pitch of notes on a string, he presses down with his finger against a partition and this makes the vibrating section of string shorter. He plays on his instrument various tunes by a successive combination of high and low notes as he shortens and lengthens the vibrating section by moving his finger up and down the sitar. Guitar, violin and sarod are stringed instruments which work this way.

Activity 11. Clamp the hacksaw blade again and make it vibrate. Now clamp it with a shorter length and listen to the note it produces. You will observe that the *shorter the length higher the pitch.*

The pitch of a string can also be raised by tightening the string. At the beginning of a performance, string instruments are tuned this way. The mass of the string also affects its frequency; where high pitch notes are required, the strings used are thin and light (less dense).

Wind instruments have air columns which vibrate just as well as strings. The flute and the shehanai are examples of wind instruments in which holes are opened and closed in order to change the length of air column that vibrates. Opening a hole has the same effect on an air column as placing a finger on a string: the pitch rises.

The length of air column in a trombone is changed as the slide moves in and out. In a trumpet or a bugle, the pressure is changed on the lips to produce different notes.

In a percussion instrument, such as a drum, tabla or mridangam, the skin is made to vibrate by stretching it. Loudness is increased by striking the skin harder, and the pitch is increased by stretching it more.

The human voice is employed as a natural musical instrument while singing. While speaking or singing, muscles alter the shape, size and tension of the vocal chords. The vocal chords vibrate as we breath out and produce sound waves.

Sound is one of the most precious gifts of man. However, by increasing the noise all around us, we are gradually losing this gift.

PROBLEMS

1. How can you show experimentally that vibration is essential for the production of sound? Give three different examples of vibration in the production of sound.
2. What is an echo? What are the conditions necessary for the production of an echo? Give a simple method of finding the speed of sound in air. What precautions would you take in conducting the experiment?
3. How will you show that a medium is necessary for the propagation of sound? In which of the three states of matter—solid, liquid and gas—is the speed of sound maximum, and in which is it minimum? Give a reason.
   The speed of sound in air is about 340 m/s. If you hear the thunder of a storm five seconds after you see the lightning, how far away is the storm raging?
4. What is the effect, if any, on the speed of sound in air if :
   (*a*) frequency of the sounding object is increased;
   (*b*) the sounding object's loudness decreases;
   (*c*) the temperature of air is raised?
5. The speed of sound in air is about 340 m/s. The ***audible*** range of frequency is 20 to 20,000 Hz. What is the range of wavelength of sound waves?
6. Describe with the aid of a diagram how dissipation of sound energy takes place from a vibrating tuning fork.
   Distinguish between transverse aud longitudinal waves and give one example of each.
7. How does a siren produce a note of constant pitch? Give a reason why the holes are evenly placed. If the disc rotates at 20 rev/s and the number of holes is 24, which note will be heard?
8. In which three ways can the pitch of a vibrating string be altered? On what factors does the loudness of a note produced by a vibrating string depend?
9. Notes produced by sitar and violin, although of the same pitch and loudness, can be distinguished from their sounds. Explain.
10. On which of the factors: mass of bob, amplitude of oscillation, length of string, does the time period of a pendulum depend? What would you do to adjust the time of a pendulum clock if it is too fast?

7

Atoms and Molecules

You are familiar with the fact that matter exists in the forms of solid, liquid and gas; these three forms are called the ***states of matter***. A very common example of a material which is known to exist in all the three forms is water. It is a liquid at normal temperatures around us, but exists as ice which is solid, and as water vapour which is a gas. A solid has a fixed shape; if one end of a scale is lifted, the other end also gets lifted. This does not happen in the case of a liquid.

Man has always been interested in matter and its forms. The early Indian thinker ***Katyayana*** and the Greek philosopher ***Democritus*** had argued that even though matter appears as a single piece, it is made up of very tiny particles.

PARTICULAR NATURE OF MATTER

Activity 1. Take a scent sprayer, a flit gun or a simple apparatus shown in diagram 57 consisting of two tubes and a bottle filled with some water. Blow hard over the top of the tube *b* through the tube *a*. You will observe that water comes out in a cloud of tiny droplets.

Take one of the droplets and view it under a powerful microscope. It looks much bigger. Can this droplet be further broken down ?

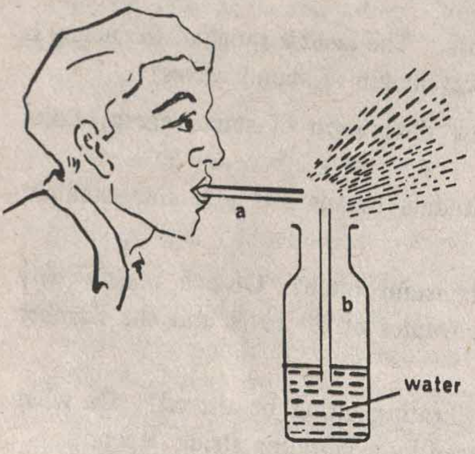


Diagram 57

Activity 2. Take a glass tube about 1 metre long and 2 cm diameter and clamp it horizontally. A piece of cotton wool soaked in a concentrated solution of ammonia is inserted at one end of the glass tubing. Another piece of cotton wool soaked in concentrated hydrochloric acid is inserted in the other (diagram 58). Observe what happens after about fifteen minutes.

You will observe that a white ring of solid ammonium chloride is formed in the glass tubing. The small particles of ammonia and hydrogen chloride gas gradually travel down the tube and form ammonium chloride where they meet. Observe the position of the ring; which of the two gas particles travel a longer distance ? How small are these particles of matter ?

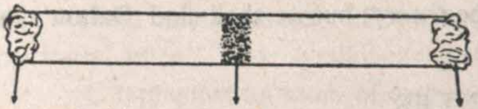

cotton wool soaked in concentrated hydorochloric acid
ring of solid ammonium chloride
cotton wool soaked in concentrated solution of ammonia

Diagram 58

Activity 3. Dissolve one gram of flourescein or potassium permanganate in a small volume of water and make up the solution to a litre (1000 cm^3). Note the colour of the solution. Take the solution in a burette and run 10 cm^3 of it drop by drop in a test tube; let us assume that it contains 200 drops. Since each drop looks coloured, it contains some of the substance. How much ?

1000 cm^3 of water contain 1 g of the substance

Hence, 10 cm^3 of water contains $\frac{10}{1000} = 0.01$ g of the substance

or 1 drop of water contains $\frac{0.01}{200} = 0.00005$ g (5×10^{-5}g) of the substance.

If you dilute the 10 cm^3 of the solution in the test tube to 1 litre, you will still detect the colour. In this case,

1000 cm^3 of the new solution contains 0.01 g of the substance

Hence, 10 cm^3 of the new solution contains $0.01 \times \frac{10}{1000} = 0.0001$ g or one drop of the new solution contains $\frac{0.0001}{200} = 5 \times 10^{-7}$ g or $\frac{1}{2}$ millionth of a gram of the substance.

In other words, 1 gram of flourescein or potassium permanganate has been subdivided into 2 million particles. Perhaps there are more than 2 million particles.

DALTON'S ATOMIC THEORY

John Dalton, in 1803, was the first to use the word ***atom*** in the modern sense. His theory may be summarised as follows :

(*a*) The smallest particle of an element is called an atom.

(*b*) An atom can neither be created nor destroyed.

(*c*) All atoms of the same element are alike, but are different from atoms of other elements.

(*d*) The smallest particles of compounds consist of small whole numbers of atoms chemically combined together.

Dalton's Atomic Theory was a very clever ***theory*** because, although there is much evidence in favour of the argument, no one has actually cut matter into individual pieces of particles. Atoms are the basic units of matter from which all objects are made; however, when we look at this book, the atoms are so tiny and closely packed that we do not distinguish individual atoms.

Much of our knowledge about matter is based upon indirect evidence obtained from a large number of observations. Discoveries made in the 20th century have led to modifications of the theory, but we shall find Dalton's theory very useful to explain chemical reactions.

ATOMS AND MOLECULES

Atoms of some elements exist singly without combination with other atoms; such elements are called ***monatomic***. For example, the noble gases helium, neon, etc., are monatomic.

Atoms of other elements cannot exist singly under normal conditions; they combine with other atoms to form bigger particles called ***diatomic***. For example, the six diatomic gases are hydrogen, oxygen, nitrogen, chlorine, bromine and iodine.

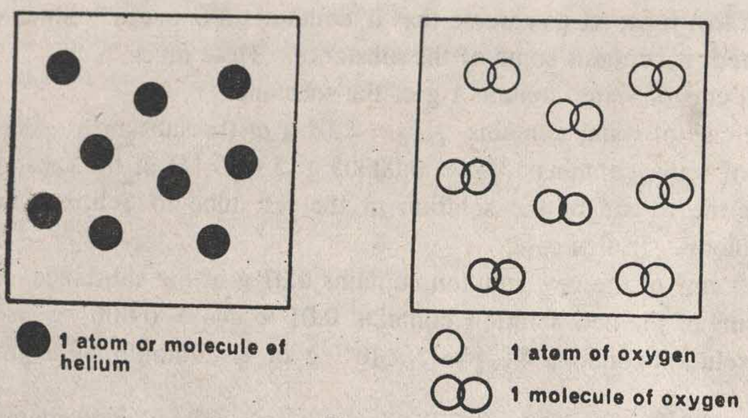


Diagram 59

Molecules of elements can have more than two atoms; these are called triatomic tetratomic, etc. depending upon the number of atoms in combination.

Molecules are the smallest particles of compounds. They contain atoms of two or more elements chemically combined. The molecule of water contains, for example, two atoms of hydrogen and one atom of oxygen. The molecule of carbon dioxide contains one atom of carbon and two atoms of oxygen.

CHEMICAL SYMBOLS

The system of short forms to indicate chemical reactions was first used by Dalton; he used circles, each with a particular mark, to represent a particular element. Nowadays, symbols are used as short forms for the names of elements. The symbol of an element also indicates an atom of the element. Usually, the symbol of an element is the first letter (***capital letter***) of the name of the element; for example,

N represents an atom of nitrogen,
O represents an atom of oxygen.

Some elements have the same first letter; hence a small letter is added to the first letter in order to avoid any confusion. For example, carbon, calcium and cobalt have the same initial letter. Their symbols are as follows:

C represents an atom of carbon,
Ca represents an atom of calcium,
Co represents an atom of cobalt.

In some cases the symbols are derived from the Latin name for the elements, for example, Cu for copper (***cuprum***), Fe for iron (***ferrum***), Pb for lead (***plumbum***), Hg for mercury (***hydragyrum***), K for potassium (***kalium***), Ag for silver (***argentum***), Na for sodium (***natrium***).

ATOMIC WEIGHTS

You have noticed in earlier experiments that the smallest particle of any substance is extremely small. An atom, which is the smallest particle of an element and which cannot be split up further by a chemical reaction must obviously be a very small particle. The weight of atoms of different elements have been found out by physicists by methods which are beyond the scope of this book. An atom of hydrogen weighs 1.67×10^{-24} g and an atom of oxygen weighs 26.5×10^{24}g. Could we have gram as the unit for the weights of atoms ?

If we were to write the actual weights of atoms in gram, it would mean working with very small numerical factors. Just as we say the distance between two definite points is 1 cm, or a certain mass to be 1 g, and compare other lengths or masses against these units, we could compare the weights of the atoms of different elements with the weight of some particle which is very light.

The hydrogen atom is the lightest atom and was, therefore, chosen as a particle to compare the weights of atoms of different elements. On this standard the atomic weight of oxygen is almost 16 which means that an atom of oxygen is sixteen times heavier than an atom of hydrogen.

In 1961, a different international standard was adopted for atomic weight according to which 1/12 of the weight of an atom of the commonest atom of carbon is the unit for comparing the weights of atoms. On this standard the atomic weights of elements are not very different from the atomic weights when they are compared with an atom of hydrogen; however, for our purpose we can take the ***atomic weight of an element as the number of times an atom of the element is heavier than an atom of hydrogen.*** Since molecules of the elements and compounds are also very light particles, molecular weight is also the number of times a molecule of an element or compound is heavier than an atom of hydrogen.

DETERMINATION OF ATOMIC WEIGHT

Chemists determine the atomic weights of elements by finding out their combining weights. In 1936, Aston, a physicist, devised a mass spectrograph by which atomic weights are measured without involving chemical reactions. In recent years better mass spectrographs have been developed which permit atomic weight measurements with extreme accuracy.

In a mass spectrograph atoms are changed into electrically charged particles. These particles are acclerated by passing through an electric field; they are then passed through a uniform magnetic field so that they get deflected and fall onto a detector (diagram 60). The heavier the charged atom, the stronger is the magnetic field required to deflect the atom onto the detector. The strength of the magnetic field needed also depends upon the charge on the atom. By a complicated mathematical relationship, which is beyond the scope of this book, the atomic weight can found out.

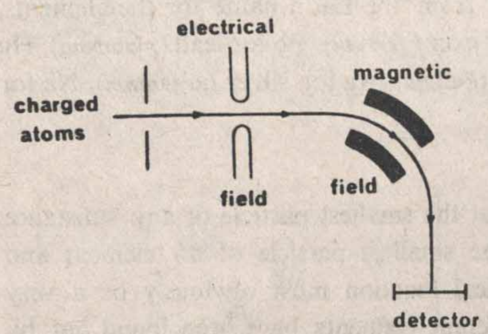


Diagram 60

These measurements of atomic weights of elements with a mass spectrograph has led to the discovery of several types of atoms of the same element. These are called isotopes. Isotopes are atoms of the same element which have identical chemical properties but different atomic weights. Hence, their discovery led to the modification of Dalton's atomic theory.

Symbols and Atomic Weights of some elements

Element	*Symbol*	*Atomic weight*
Aluminium	Al	27
Argon	Ar	40
Barium	Ba	137
Bromine	Br	80
Calcium	Ca	40
Carbon	C	12
Chlorine	Cl	35.5
Chromium	Cr	52
Copper	Cu	64
Fluorine	F	19
Gold	Au	197
Helium	He	4
Hydrogen	H	1
Iodine	I	127

Iron	Fe	56
Lead	Pb	207
Lithium	Li	7
Magnesium	Mg	24
Manganese	Mn	55
Mercury	Hg	201
Neon	Ne	20
Nitrogen	N	14
Oxygen	O	16
Phosphorus	P	31
Potassium	K	39
Radium	Ra	226
Silicon	Si	28
Silver	Ag	108
Sodium	Na	23
Sulphur	S	32
Tin	Sn	119
Uranium	U	238
Zinc	Zn	65

PROBLEMS

1. What experimental evidences lead us to believe that matter is made up of a very large number of small separate particles ?
2. What is Dalton's Atomic Theory ? Why is it called a theory ? Give one example in which respect the theory has been modified.
3. How does Dalton's Atomic Theory explain the difference between an atom and a molecule ?
   Atoms of some elements exist singly while of other elements exist in combination with other atoms. Give examples to explain this statement.
4. What is meant by the atomic weight of an element ? What do you understand by the statement : atomic weight of oxygen is 16 ? Why is the atomic weight not written in grams ?
5. What are chemical symbols ? What do they denote ? Write the chemical symbols of sodium, lead, chlorine, phosphorus, silicon and iron.

8 Electricity and Chemical Change

You have studied earlier that electricity passes readily through metallic elements. Copper and aluminium cables are used to bring electricity to our houses. While they get heated up by the passage of electricity through them, they do not undergo any chemical change.

Non-metallic elements are generally bad conductors (insulators) of electricity; however, carbon in the form of graphite is a good conductor of electricity.

CONDUCTION OF ELECTRICITY THROUGH COMPOUNDS

Activity 1. Connect two platinum wires to a 6-volt battery; with an ammeter reading up to 2 amperes in series (diagram 61). Take distilled water in a beaker and dip the wires for a moment into it. Does the needle of the ammeter show any deflection?

Repeat the experiment taking the following liquids in place of water: (*a*) alcohol, (*b*) dilute hydrochloric acid, (*c*) dilute sulphuric acid, (*d*) sugar solution in water, (*e*) sodium chloride solution in water, (*f*) copper sulphate solution in water.

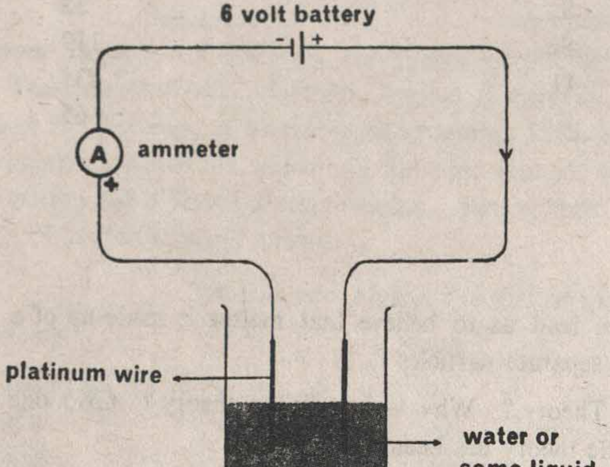


Diagram 61

Remember to wash the platinum wire and the beaker with distilled water after they have been used with a liquid. Which of the liquids conduct electricity and which do not? Is there any indication of a chemical change taking place?

You will observe that distilled water, alcohol and sugar solution do not conduct electricity. Solutions of sodium chloride and copper sulphate, dilute hydrochloric acid and dilute sulphuric acid conduct electricity.

Activity 2. Connect two carbon rods (these could be obtained from used torch cells) to a 6-volt battery through an ammeter. Fill a crucible about 2/3rd with solid lead bromide and dip the rods into it. Melt the lead bromide by heating it with a bunsen burner (diagram 62). Does a current flow through solid lead bromide? Notice any change in the current when the lead bromide melts.

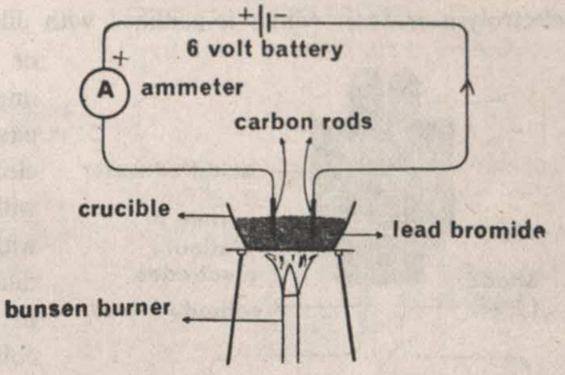


Diagram 62

Lead bromide is slightly soluble in water. Dissolve a small amount of lead bromide in water and see if it conducts electricity by performing an experiment similar to the one described above. Is there any sign of a chemical change taking place in the experiments?

You will observe that lead bromide solution in water and molten lead bromide both conduct electricity. Classify materials into two groups. Those which conduct electricity either in the molten state or when dissolved in water, and those which do not conduct electricity.

In the above experiments you will notice that when the compounds conduct electricity evolution of gases takes place at the platinum wire and at the carbon rod. This clearly indicates a chemical decomposition of the compound which conducts electricity.

ELECTROLYSIS

Compounds which conduct electricity when they are in molten state or when dissolved in water, and undergo chemical decomposition by the flow of electrical energy, are called ***electrolytes.*** Compounds which do no conduct electricity when in the molten state or when dissolved in water are called ***non-electrolytes.*** Water is a non-electrtolyte at low voltages although it conducts electricity at a very high voltage.

The process of conduction of electricity through an electrolyte, which undergoes a chemical decomposition by the flow of electricity, is called ***electrolysis.*** The apparatus used for electrolysis is called a ***voltameter.*** Molten sodium chloride and and molten copper sulphate can also conduct electricity but it is not possible to melt these substances with the flames available in the laboratories.

The metal or carbon rods used in the electrolysis are called ***electrodes.*** The electrode connected to the positive terminal of the battery is called the ***anode*** while the electrode connected to the negative terminal is called the ***cathode.*** Platinum and carbon electrodes are used in electrolysis because usually they react neither with the electrolyte nor with the products of electrolysis.

ELECTROLYSIS OF ACIDIFIED WATER

Activity 3. Different types of apparatus have been used to study the effect of electrolysis of water which is acidified with dilute sulphuric acid. Either platinum or carbon electrodes can be used. In one apparatus two carbon electrodes pass through a vessel. Connect the electrodes with a 6-volt battery in series with an ammeter. The vessel is filled with water containing a few drops of dilute sulphuric acid. Allow the current to pass for at least 15 minutes and collect the gases in the test tubes by displacing water (diagram 63).

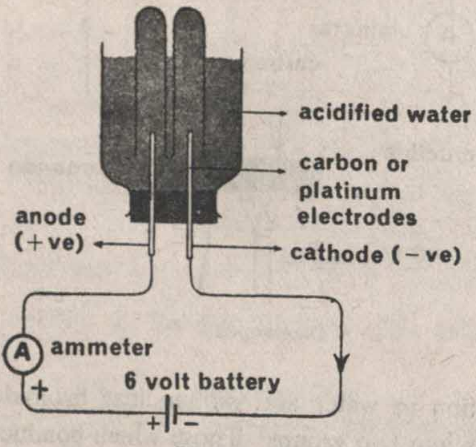


Diagram 63

Compare volumes of the two gases. Test the gas liberated at the anode with a glowing splint and the gas liberated at the cathode with a burning splint. You will notice that the gas evolved at the anode is oxygen and the gas liberated at the cathode is hydrogen. Oxygen and hydrogen are in the ratio of 1:2 by volume. The products indicate that water has been decomposed into oxygen and hydrogen during electrolysis.

ELECTROLYSIS OF COPPER CHLORIDE SOLUTION

Activity 4. Fill a U-tube with 30 per cent solution of copper chloride in water. Dip two platinum electrodes into the solution and connect the electrodes to a 10-volt battery and an ammeter (diagram 64).

You will observe that the cathode is deposited with a brown coating which is the copper metal. There is an evolution of a greenish yellow gas around the anode, which comes out of the U-tube and can bleach moist litmus paper. This gas is chlorine.

ELECTROLYSIS OF MOLTEN LEAD BROMIDE

Activity 5. Fill a small crucible half full with solid lead bromide.

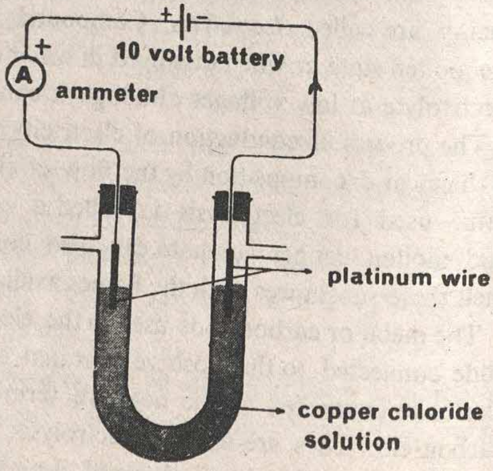


Diagram 64

Insert in it a steel cathode and a carbon anode. The electrodes are connected to a 12-volt battery in series with an ammeter and a variable resistor (diagram 65). Heat the lead bromide until it melts. Adjust the variable resistor until the current flowing through the circuit is 3 amperes. After about 15 minutes you will notice red vapours of bromine around the anode and grey metallic lead deposited on the cathode. The metal leaves a black mark when scratched on a piece of paper.

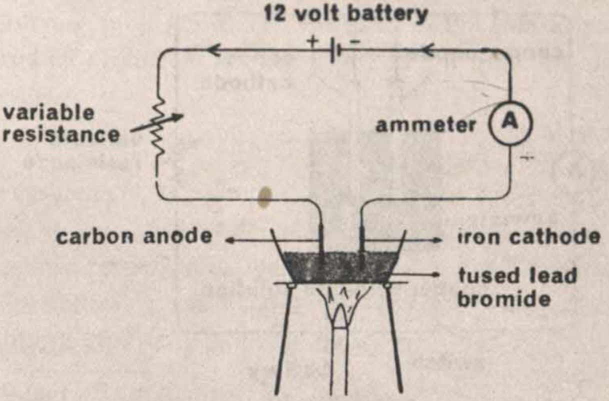


Diagram 65

ATOMS AND IONS

Why do electrolytes conduct electricity? The electrolytes contain charged particles, with positive and negative changes, which are attracted by the electrodes having opposite charges. These charged particles are responsible for the conduction of electricity.

Charged atoms or groups of atoms are called ***ions***. The positively charged ions are called ***cations*** because they are attracted towards the cathode during electrolysis. The negatively charged ions are called ***anions*** as they are liberated at the anode during electrolysis. It is observed that *hydrogen and metallic ions are liberated at the cathode; they are, therefore, positively charged ions. Non-metallic ions are liberated at the anode and are, therefore, negatively charged ions.*

Is sodium the same as the sodium ion present in sodium chloride? Is the copper atom the same as the copper ion present in copper sulphate? When we drop a piece of sodium metal (containing atoms of sodium) in water, there is a vigorous reaction and hydrogen gas is produced. When sodium chloride is added to water, however, there is no reaction between the sodium ion and water. Similarly, copper metal containing atoms of copper is brown but copper ions in copper sulphate are blue in colour. Thus, atoms and ions have different properties. Atoms are electrically neutral whereas ions are charged particles. It would therefore appear that the charge carried by an ion is responible for its different chemical property.

FIRST LAW OF ELECTROLYSIS

Activity 6. Clean with sand paper two strips of thin copper sheets each 5 cm × 10 cm in area, and weigh them separately. The sheets are connected to a

4-volt battery in series with an ammeter reading upto 2 amperes, a variable resistor and a switch. Immerse the sheets into copper sulphate solution and clamp them in position (diagram 66).

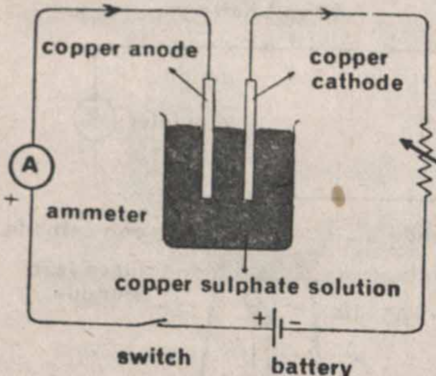


Diagram 66

Switch on the electricity and immediately start recording the time with the help of a watch or a clock. Operate the variable resistor to maintain a constant current of about 1 ampere. After 30 minutes, switch off the current. Remove the electrodes, taking care that you do not touch the portions of the copper electrodes which were submerged in the solution. You will notice the pink colour of the copper deposited on the cathode. Dip the electrodes first into a beaker containing distilled water and then into a beaker of alcohol. Hold the electrodes in air when the alcohol quickly evaporates and leaves them dry. Weigh each electrode again separately.

You will notice that the cathode has gained weight while the anode has lost equal weight. Repeat the experiment to measure the mass of copper deposited when (*a*) the current is different, and (*b*) when the time of passage of electricity is different.

The quantity of electricity, i.e., the amount of electrical charge measured in coulomb passing through an electrolyte during electrolysis is equal to the product of the current measured in amperes and the time in seconds. Thus,

$$\underset{\text{(coulomb)}}{\textit{quantity of electricity}} = \underset{\text{(ampere)}}{\textit{current}} \times \underset{\text{(second)}}{\textit{time}}$$

The observations show that *the mass of substance liberated depends upon both the current and the time of passage of current, i.e., it is directly proportional to the quantity of electricity.* If the current is doubled while the time remains unchanged, the mass liberated will also double. If the current is halved but the time is doubled, the copper deposited will not alter. We write this First Law of Electrolysis mathematically as follows :

$$\textit{mass of substance liberated, } m \propto \textit{quantity of current, } I$$

$$\text{also} \quad m \propto \textit{time of passage of current, } t$$

$$\text{or} \quad m \propto \textit{quantity of electricity, } Q$$

If a similar experiment is performed using silver electrodes dipping in silver nitrate solution, you will observe that silver is deposited on the cathode while the anode shows an equal loss in weight. By suitable accurate methods, which are beyond the scope of this book, the mass of gases liberated in electrolysis by a certain quantity of electricity can also be determined. In all these cases it is found that the First Law of Electrolysis holds good, i.e., the mass of the substance liberated is proportional to the product of current and time; greater the quantity of electricity more is the mass deposited.

VALENCY

Faraday is a bigger unit for the measurement of quantity of electricity and equals 96,500 coulombs. ***Gram-atomic weight*** is defined as the mass in gram equal to the atomic weight of an element. Accurate experiments performed by using different electrolytes and electrodes show the following results between the mass liberated (measured in gram) and the quantity of electricity passed (measured in faraday):

Name of the element	*Mass of the element in gram (gram-atomic weight)*	*Quantitv of electricity passed in faraday*
Hydrogen	1	1
Oxygen	16	2
Chlorine	35.5	1
Sodium	23	1
Silver	108	1
Copper	64	2
Zinç	65	2
Aluminium	27	3

We notice that the quantity of electricity needed to liberate one gram atomic weight of any element is one faraday or a simple multiple of this quantity. This number is called the ***valency*** of the element. The valency of an element denotes its ***combining power*** in a chemical reaction and is equal to the quantity of electricity (measured in faraday) required to liberate one gram-atomic weight of an element.

For example, 1 faraday of electricity is required to liberate 108 grams of silver which is its gram-atomic weight; the valency of silver is, therefore, 1, or it is a monovalent element. Oxygen is a divalent element because one gram-atomic weight of this element (16 g) is liberated during electrolysis of water when 2 faraday of electricity is passed through acidulated water.

RADICALS

There are groups of elements called ***radicals*** which go into combination as single units; they have combining power or valency like any other element. Unlike atoms, however, the radicals do not have a separate existence under ordinary conditions.

For example, a sulphate radical contains one atom of sulphur and four atoms of oxygen. It has a valency of 2. The following chart gives the valencies of some metallic and non-metallic elements and radicals. It is of interest to note that some elements such as copper and iron have more than one type of combining powers.

VALENCY CHART

Valency	*Metallic*	*Non-Metallic*
1	Sodium Na Potassium K Silver Ag Copper I (Cuprous) Cu Ammonium NH_4	Chloride Cl Bromide Br Iodide I Hydrogen H Hydroxide OH Bicarbonate or hydrogen carbonate HCO_3 Bisulphate or hydrogen sulphate HSO_4 Bisulphite or hydrogen sulphite HSO_3 Bisulphide or hydrogen sulphide HS Nitrate NO_3 Nitrite NO_2 Chlorate ClO_3
2	Magnesium Mg Calcium Ca Zinc Zn Barium Ba Copper II (Cupric) Cu Iron II(Ferrous) Fe Lead II(Plumbous) Pb Mercury II(Mercuric) Hg Tin II(Stannous) Sn	Carbonate CO_3 Sulphate SO_4 Sulphite SO_3 Sulphide S Oxide O
3	Aluminium Al Iron III(Ferric) Fe	Nitrogen N Phosphate PO_4
4	Lead IV (Plumbic) Pb Tin IV(Stannic) Sn	Carbon C Silicon Si

ELECTROLYSIS IN INDUSTRY

Metallic articles are coated with a thin layer of another element by the process of electrolysis. This process is called ***electroplating***. Articles made of iron and steel are coated with silver, nickel or chromium to improve their appearance and to prevent them from rusting.

Several metals are obtained from their compounds by electrolysis. Many useful compounds are also obtained by passing electricity through other compounds.

PROBLEMS

1. What are the differences between a conductor of electricity and an electrolyte? Which of the following are conductors and which are electrolytes : lead nitrate, zinc, nitric acid, ammonium hydroxide, magnesium and graphite?
2. Why are platinum and carbon electrodes generally used in electrolysis? Name the products formed at the two electrodes when electricity is passed through the following : (*a*) molten sodium chloride, (*d*) concentrated solution of copper chloride, (*c*) molten aluminium oxide, and (*d*) concentrated hydrochloric acid.
3. What are ions? How do they differ from atoms? What are the two types of ions? Why are they so called?
4. For how long should a current of 1.93 A flow in order to deposit 1.08 g of silver by electrolysis?
5. What is meant by valency of an element or a radical, Give two examples of each.

9

Chemical Equations

According to the atomic theory, molecules of compounds are formed by a combination of atoms of different elements in small whole numbers. Suitable experiments can lead to the determination of weights of different elements which combine to form a compound.

EMPIRICAL OR SIMPLEST FORMULA

Activity 1. When magnesium burns in air, it combines with oxygen of the air to form magnesium oxide. Magnesium is first weighed in a crucible and is burnt in air. The white ash of magnesium oxide is weighed along with the crucible. In one experiment, the following results were obtained :

mass of magnesium $= 0.264$ g
mass of magnesium oxide $= 0.44$ g

Hence, mass of oxygen in magnesium oxide $= 0.44 - 0.264 = 0.176$ g. We know that the atomic weights of magnesium and oxygen are 24 and 16, respectively while they combine in the ratio of 0.264 g to 0.176 g. Hence, the ratio of atoms of magnesium and oxygen in magnesium oxide is

$$\frac{0.264}{24} : \frac{0.176}{16} \text{ or } 0.011 : 0.011$$

Thus, equal number of atoms of magnesium and oxygen combine to form magnesium oxide. The ***simplest or empirical formula*** of a compound is the formula that shows the number of atoms of different elements present in one molecule of the compound in the simplest numerical ratio. In the above example, the simplest formula of magnesium oxide is MgO.

MOLECULAR FORMULA

The empirical formula of a compound does not necessarily show the actual number of atoms of different elements present in one molecule of the compound. For example, the empirical formula of hydrogen peroxide is HO; this means that a molecule of hydrogen peroxide contains equal number of atoms of hydrogen and oxygen. Actually, a molecule of hydrogen peroxide contains two atoms of hydrogen and two atoms of oxygen.

The ***true or molecular formula*** of a compound is the formula which expresses the actual number of each kind of atom present in one molecule of the compound. Thus, the molecular formula of hydrogen peroxide is H_2O_2. In the case of compounds formed by a combination of metallic and non-metallic elements or radicals the molecular formula is generally the same as the empirical formula.

VALENCY AND FORMULA

You have noticed that the formula of any compound can be deduced by determining the composition of the compound experimentally as in the case of magnesium oxide. The formula of compounds, particularly formed by the combination of metallic and non-metallic elements or radicals, can also be deduced with the help of valencies. For example, write the symbol of the metallic part first and then write the symbol of the non-metallic part. Put the valency of one part at the base of the symbol of the other. Thus, the valency numbers are interchanged.

Example 1. The formula of sodium oxide. The valencies of sodium and oxygen are 1 and 2, respectively. The symbol of metallic sodium is written first and the valency of oxygen (2) put at the base of its symbol. Then the symbol of oxygen is written. When no number is put at the base of the symbol, it is understood that the number is 1, which is the valency of sodium in this case.

Hence, the simplest formula of sodium oxide is Na_2O.

Example 2. The formula of zinc oxide. The valencies of both zinc and oxygen are 2. The formula of zinc oxide will be Zn_2O_2. Simplifying by the division of the common factor 2, we obtain the simplest formula of zinc oxide as ZnO.

Example 3. The formula of ammonium carbonate. When a radical, which is a group of elements, is to be shown doubled or trebled, it is put in brackets. The metallic radical ammonium is written first and this is put in brackets as the valency of carbonate, which is 2, is to be put at its base. This is followed by the symbol of carbonate and this is not put in brackets as the valency factor of ammonium is 1. Thus, the formula of ammonium carbonate is $(NH_4)_2CO_3$.

Example 4. The formula of calcium carbonate. The valencies of both calcium and carbonate are 2. The formula of calcium carbonate is $Ca_2(CO_3)_2$. However, cancelling the common factor 2, the formula of calcium carbonate is $CaCO_3$. It is important to remember that the combination of atoms is not necessarily determined by valencies alone. The formula deduced on the basis of valencies may not exist at all. For instance, both sulphur and oxygen are divalent and the formula of the compound formed by the two elements should be SO. In fact, no such compound with this composition exists. There are two oxides of sulphur which have the formula SO_2 and SO_3. Another example is the existence of carbon monoxide with the composition CO which would not be possible according to the valencies of carbon and oxygen. Generally, however, valency is a useful tool for deducing the formula of compounds.

NUMBER OF ATOMS IN A COMPOUND

The formula of sodium oxide is Na_2O. The formula suggests that a molecule of the compound contains 2 atoms of sodium and one atom of oxygen. The formula of ammonium carbonate is $(NH_4)_2CO_3$. A molecule of this compound contains 2 atoms of nitrogen, 8 atoms of hydrogen, 1 atom of carbon and 3 atoms of oxygen. A molecule of ammonium nitrate NH_4NO_3 contains 2 atoms of nitrogen, 4 atoms of hydrogen and 3 atoms of oxygen.

If a number is put in front of the formula of a compound, the number of different kinds of atoms present in a molecule is multiplied by that number. For example, $2\,Na_2O$ represents 4 atoms of sodium and 2 atoms of oxygen. $3\,(NH_4)_2CO_3$ represents 6 atoms of nitrogen, 24 atoms of hydrogen, 3 atoms of carbon and 9 atoms of oxygen. Similarly, $4NH_4NO_3$ represents 8 atoms of nitrogen, 16 atoms of hydrogen and 12 atoms of oxygen.

CHEMICAL EQUATIONS

The results of a chemical change can be represented by the symbols of elements and formulae of compounds of the reactants and the products. The reactants are written on the left and the products are written on the right side of the sign = or →. This representation of a reaction is called a chemical equation.

Chemical equations are written after a reaction has been established experimentally, and after all the reactants and the products have been analysed and their formulae deduced. Since a large number of chemical reactions are known, it is possible to produce equations for reactions on the basis of some established principles. Rules for writing the chemical equations are as follows :

(*a*) The names of the reactants and the products of the chemical reaction must be known.

(*b*) The six elements, hydrogen, nitrogen, oxygen, chlorine, bromine, and iodine when not combined with any other elements must be represented as diatonic molecules. We put the number 2 at the base of their symbol on the right side and write the symbol as H_2, N_2,$)_2$, Cl_2, Br_2, I_2.

(*c*) Symbols only for all other elements and formulae for the compounds (taking valencies of the metallic and non-metallic parts into consideration) involved in the reaction are written.

(*d*) Numbers, if necessary, are inserted before each symbol or formula so that the number of different kinds of atoms in the reactants and products remains unaltered. This step is called ***balancing the equation*** and is based on the ***law of conservation of mass***. According to the law, matter is neither created nor destroyed in a chemical reaction; therefore, the number of different kinds of atoms should be the same before and after a chemical reaction.

EXAMPLES OF CHEMICAL EQUATIONS

(1) It has been experimentally been found out earlier that when hydrogen burns in oxygen the product is water. The equation in words for the reaction is written as follows :

hydrogen + oxygen = water

Using symbols for hydrogen and oxygen as diatomic molecules when in uncombined state, as reactants, and writing the formula for water (valency considered) the equation will be as follows :

$$H_2 + O_2 \rightarrow H_2O$$

In the above equation there are two oxygen atoms on the left hand side and only one atom on the right hand side. To have equal number of oxygen and hydrogen atoms on the two sides, the balanced equation will be :

$$2H_2 + O_2 = 2H_2O$$

Balancing an equation is a matter of practice only; generally small numbers upto 5 are involved in balancing of equations.

(2) When sodium reacts with water, the prodctus are sodium hydroxide and hydrogen. The equation in words for the reaction will be :

sodium + water = sodium hydroxide + hydrogen

Using symbols and formula, when valencies are taken into consideration, of substances, the equation is :

$$Na + H_2O \rightarrow NaOH + H_2$$

To make it a balanced equation, numbers have to be inserted before symbols and formulae. Hence, we obtain:

$$2Na + 2H_2O = 2NaOH + H_2$$

It must be remembered that we cannot put any number on the right side of symbol of an element, or change the formula of a compound, just to balance an equation.

INFORMATION FROM A CHEMICAL EQUATION

A chemical equation provides much information about a chemical reaction. For example, consider the equation :

$$2H_2 + O_2 = 2H_2O$$

The equation gives us the following information :

(*a*) Hydrogen combines with oxygen to form water.

(*b*) Two molecules of hydrogen combine with one molecule of oxygen to form two molecules of water.

(*c*) A molecule of hydrogen contains two atoms, a molecule of oxygen contains two atoms, and a molecule of water contains two atoms of hydrogen and one atom of oxygen in combination.

(*d*) 4 atoms of hydrogen, i.e., 4 parts by weight of hydrogen combine with

2 atoms of oxygen, i.e., 32 parts by weight of oxygen to form 2(2 + 16) or 36 parts by weight of water.

LIMITATIONS OF A CHEMICAL EQUATION

(*a*) A chemical equation does not tell us the physical state of the substances, i.e., whether the substances involved are solids, liquids or gases.

(*b*) It does not tell us about the conditions necessary to bring about a particular chemical reaction. A reaction may be dangerous and precautions may have to be taken for the reaction to take place safely.

(*c*) An equation does not specify whether heat energy is evolved or absorbed in the chemical reaction.

(*d*) It does not mention what percentage of the reactants will form the products.

APPLICATION OF A CHEMICAL REACTION

Chemical equations are extremely important because it is possible to find out from them the amount of a product formed from a given amount of a reactant. In industries it is important that the actual yield of a product should be as close as possible to the yield calculated by a chemical equation. Let us attempt to calculate the amounts of the products and the reactants with the help of a chemical equation.

Example 1. To calculate the weight of calcium oxide formed when 20 g of calcium carbonate is strongly heated.

$$\begin{array}{lcccc} & \dfrac{\mathrm{CaCO_3}}{40+12+48} & = & \dfrac{\mathrm{CaO}}{40+16} & + \underline{\mathrm{CO_2}} \\ \text{or} & 100 & & 56 & \end{array}$$

The chemical equation shows that 100 g of calcium carbonate is formed from 56 g of calcium oxide. Hence 20 g of calcium carbonate is formed from :

$$\frac{56}{100} \times 20 = 11.2\text{ g of calcium oxide.}$$

Example 2. To calculate the weight of zinc sulphate formed when 6.5 g of zinc completely reacts with dilute sulphuric acid, and also to find out the weight of hydrogen liberated during the reaction.

Chemical equation for the reaction is as follows :

$$\frac{\mathrm{Zn}}{65} + \underline{\mathrm{H_2SO_4}} \longrightarrow \frac{\mathrm{ZnSO_4}}{65+32+64} + \frac{\mathrm{H_2}}{2}$$

65 g of zinc form 161 g of zinc sulphate and 2 g of hydrogen.

Hence, 6.5 g of zinc form 16.1 g of zinc sulphate and 0.2 g of hydrogen.

Example 3. To calculate the weight of pure sulphuric acid which reacts completely with 4 g of copper oxide.

$$\frac{\mathrm{CuO}}{64+16} + \frac{\mathrm{H_2SO_4}}{2+32+64} \longrightarrow \underline{\mathrm{CuSO_4}} + \underline{\mathrm{H_2O}}$$

80 g of copper oxide react with 98 g of sulphuric acid.

Hence, 4 g of copper oxide react with $\frac{98}{80} \times 4 = 4.9$ g of sulphuric acid.

TYPICAL CHEMICAL REACTIONS

Some typical chemical reactions are useful to consider and study. We shall now attempt to write their chemical equations.

1. *Synthesis.* When a compound is formed from its simpler parts, the reaction is called synthesis. Examples are :

(*a*) Nitrogen combines with oxygen to form ammonia gas.

$$N_2 + 3H_2 = 2NH_3$$

(*b*) Magnesium burns in oxygen to form magnesium oxide.

$$2Mg + O_2 = 2MgO$$

2. *Action of water on metals.*

(*a*) Metals like sodium, potassium and calcium react with water at room temperature to form hydroxide of the metal and hydrogen.

$$2Na + 2H_2O = 2NaOH + H_2$$

$$Ca + 2H_2O = Ca(OH)_2 + H_2$$

(*b*) Heated magnesium and zinc react with steam to form their oxide and liberate hydrogen. For example,

$$Mg + H_2O = MgO + H_2$$

(*c*) Steam reacts with red hot iron to form a black oxide of iron called tri-iron tetroxide and hydrogen.

$$3Fe + 4H_2O = Fe_3O_4 + 4H_2$$

3. Dilute hydrochloric acid and dilute sulphuric acid react with the more reactive elements, e.g., lead and above in the reactivity series, to form the salt of the acid and hydrogen. For example,

$$Zn + 2HCl = ZnCl_2 + H_2$$

4. An acid reacts with a base to form a salt and water. The three acids which are generally used in a chemistry laboratory are hydrochloric acid, HCl, sulphuric acid H_2SO_4, and nitric acid, HNO_3. Their salts are the chlorides, sulphates and nitrates respectively.

Metallic oxides and hydroxides generally behave as bases. When hydrochloric acid reacts with sodium oxide, the products are sodium chloride and water.

$$Na_2O + 2HCl \rightarrow 2NaCl + H_2O$$

When sulphuric acid reacts with magnesium hydroxide, the products are magnesium sulphate and water.

$$Mg(OH)_2 + H_2SO_4 \rightarrow MgSO_4 + 2H_2O$$

5. Acids react with carbonates and bicarbonates to form a salt, water and carbon dioxide. For instance, sodium carbonate on reacting with nitric acid forms

sodium nitrate, water and carbon dioxide.

$$Na_2CO_3 + 2HNO_3 \rightarrow 2NaNO_3 + H_2O + CO_2$$

Magnesium bicarbonate will react with hydrochloric acid to form magnesium chloride, water and carbon dioxide.

$$Mg(HCO_3)_2 + 2HCl \rightarrow MgCl_2 + 2H_2O + 2CO_2$$

6. *Double decomposition reactions.* In such reactions two new substances are formed by the combination of the metallic part of one substance with the non-metallic part of another substance. For example, silver nitrate reacts with sodium chloride to form silver chloride and sodium nitrate.

$$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$$

Very often an insoluble compound is formed by this method.

7. *Decomposition.* A compound decomposes into simpler substances in some chemical reactions. Examples are the following:

(*a*) The carbonates of most metals except sodium and potassium carbonates form an oxide and carbon dioxide on heating. For instance,

$$CaCO_3 \rightarrow CaO + CO_2$$

(*b*) Nitrates of heavy metals on heating produce an oxide, nitrogen dioxide and oxygen. For instance,

$$2Pb(NO_3)_2 \rightarrow 2PbO + 4NO_2 + O_2$$

(*c*) Metallic hydroxides except sodium and potassium hydroxide decompose on heating to form an oxide and water. For example,

$$Cu(OH)_2 \rightarrow CuO + H_2O$$

PROBLEMS

1. A compound was found to contain 13.5 g of aluminium and 53.25 g of chlorine. Calculate the simplest formula of the compound.
2. A compound contains 28g of iron 16 g of sulphur. Calculate its simplest formula.
3. Write the formula of the following compounds : cupric (Copper II) sulphate, ferrous (Iron II) chloride, barium nitrate, calcium carbonate, ammonium hydroxide, calcium phosphate and zinc oxide.
4. Count the number of atoms of different elements in the following formulae: $4BaCl_2$, $3Cu(NO_3)_2$, $2NH_4NO_3$, $2Fe_2(SO_4)_3$ and $4(NH)_2CO_2$.
5. What information do you get from a chemical equation? What are the limitations of an equation? Illustrate your answer with the help of an example.

6. Write balanced equations for the following word equations :
   - (*a*) potassium + water → potassium hydroxide + hydrogen
   - (*b*) magnesium + hydrochloric acid → magnesium chloride + hydrogen
   - (*c*) calcium oxide + hydrochloric acid → calcium chloride + water
   - (*d*) calcium bicarbonate + hydrochloric acid → calcium chloride + water + carbon dioxide
   - (*e*) copper nitrate → copper oxide + nitrogen dioxide + oxygen
   - (*f*) lead nitrate + sulphuric acid → lead sulphate + nitric acid
7. Calculate the weight of iron sulphate formed when 24 g of sulphuric acid completely react with excess of iron.
8. How much of magnesium sulphate will be formed when 6 g of magnesium react with sulphuric acid? What weight of sulphuric acid is needed in this preparation?
9. How much of copper oxide is formed when 18.8 g of copper nitrate is completely decomposed by heating?

10 Chemistry of Rocks and Minerals

The earth is a treasure house of chemical materials. These materials contain the various elements generally in chemical combinations. Oxides and salts of most of the elements are found in abundance from which the compounds are manufactured by bringing about necessary chemical reactions. Sulphur occurs as an element free in nature. Gypsum, which is a mineral form of calcium sulphate, is used as a source for preparing sulphur. Bauxite, a mineral containing aluminium oxide, is used in the extraction of aluminium. Haematite, a mineral containing ferric (iron III) oxide, is used to obtain iron and steel. These are some of the many useful minerals.

SOURCES OF CALCIUM CARBONATE

Calcium carbonate is abundantly found in nature in the form of rock formations like chalk, limestone and marble. The mineral Iceland Spar, also called Calcite, is a very pure form of calcium carbonate. (The chalk mentioned here is very different from the black-board chalk which is mainly calcium sulphate.)

Some sea organisms like corals and molluscs take in calcium compounds dissolved in sea water to build their shells and other hard parts. When these animals die, they sink to the bottom of the water and decompose. Their hard part and the shell remain deposited at the sea bed. This deposit becomes thicker over a period of thousands of years. Owing to the upheavals of the earth's crust these deposits are raised and become ***chalk*** hills. Some chalk deposits are subjected to high pressures due to other deposits and high temperatures inside the earth ; these change to ***limestone***. Some rocks however are subjected to very high temperature and pressure; these change to ***marble***. Thus, chalk, limestone and marble are different stages of change taking place in the same chemical substance, calcium carbonate. Chalk is soft and powdery, limestone is hard and stony while marble is very hard and crystalline.

ACTION OF HEAT ON CHALK OR LIMESTONE

Activity 1. Heat strongly some powdered chalk or limestone in a hard glass test tube. Pass the gas liberated into a test tube containing lime water (diagram 67). The lime water turns milky showing that carbon dioxide gas is given out.

Allow the residue in the test tube to cool. Transfer it into an evaporating dish. Add a few drops of water on to the solid. You will notice that the solid crumbles to powder, swells up and becomes very hot. You may observe steam also coming out. Calcium carbonate in any form, on heating strongly changes to calcium oxide, called ***quicklime.*** Carbon dioxide gas is liberated.

$$CaCO_3 \rightarrow CaO + CO_2$$

The white powder obtained when quick lime is treated with a small amount of water is chemically calcium hydroxide and is called ***slaked lime.***

$$CaO + H_2O \rightarrow Ca(OH)_2$$

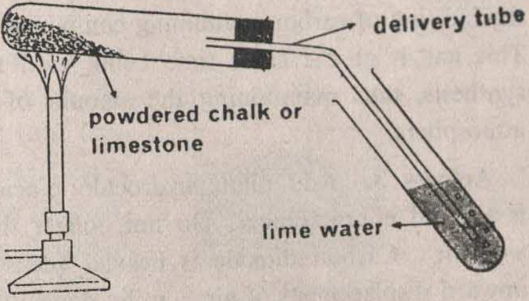


Diagram 67

Activity 2. Take a small amount of slaked lime in a test tube, add about half a test tube full of distilled water and shake well. Filter and test the filtrate with red litmus paper. The filtrate turns red litmus blue showing that calcium hydroxide is slightly soluble in water. Most of the calcium hydroxide does not dissolve in water. The solution of calcium hydroxide in water is called ***lime water.***

USES OF LIME

Large quantities of quicklime and slaked lime are prepared by strongly heating limestone and chalk in lime-kilns. The heating produces quick lime which is then converted to slaked lime by treatment with water.

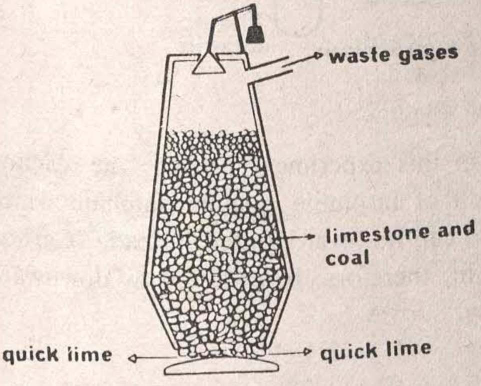


Diagram 68

The soft paste made by mixing slaked lime, sand and water is called ***lime mortar***, and is used for holding bricks together in building structures. A thick suspension of slaked lime in water is used for whitewashing buildings. Both these uses are based on the fact that calcium hydroxide combines with carbon dioxide of the air to form a hard layer of calcium carbonate. Slaked lime is used in agriculture for removing the acidity of the soil and for better drainage through clay soils.

Limestone is mixed with clay and is finely powdered. The mixture is made into a thick paste with water and is heated strongly in a rotating furnace. This produces cement, an important building material.

PREPARATION OF CARBON DIOXIDE

You have learnt that carbon dioxide is being added to the atmosphere due to the burning of carbon containing compounds and by respiration of living beings. This gas is at the same time being used up by plants in the process of photosynthesis, thus maintaining the amount of carbon dioxide fairly constant in the atmosphere.

Activity 3. Add dilute hydrochloric acid to marble or limestone chips. There is a rapid effervescence. Do not collect the gas immediately, as it will be mixed with air. Carbon dioxide is heavier (denser) than air. Hence it is collected by upward displacement of air, i. e. by downward delivery (diagram 69). A solution of calcium chloride is left in the flask.

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

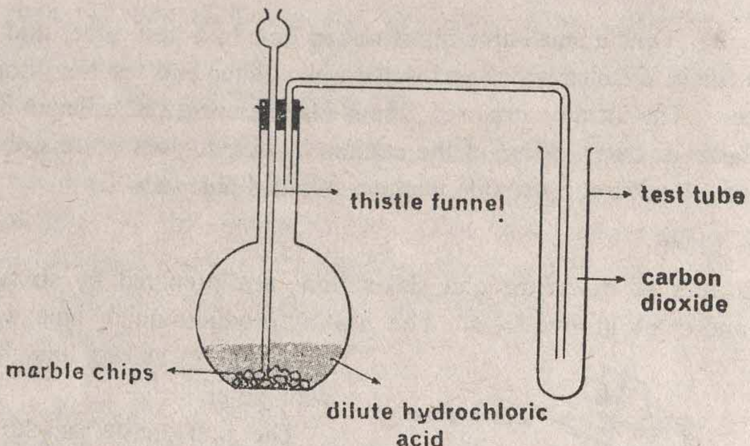


Diagram 69

Dilute sulphuric acid cannot be used in this experiment because the reaction stops after a while owing to the formation of insoluble calcium sulphate which covers the marble chips. Dilute nitric acid can however be used instead. Carbon dioxide is not very soluble in water; it can, therefore, be collected by downward displacement of water if it is not needed dry.

PROPERTIES OF CARBON DIOXIDE

(*a*) Carbon dioxide is present in air in small amounts. The gas is colourless and odourless.

(*b*) Introduce a lighted splint into a test tube filled with the gas; you will notice that the splint is extinguished. The gas neither burns nor supports combustion.

(*c*) Invert a test tube filled with carbon dioxide into a beaker containing water. After few minutes you will notice that the water level rises slightly into the test tube. This shows that carbon dioxide is soluble in water. Under normal conditions of temperature and pressure, one volume of carbon dioxide dissolves in one volume of water (diagram 70). If carbon dioxide is bubbled into a test tube containing distilled water for some time and then a drop of blue litmus solution is added to the solution, the litmus turns dull red. The gas when dissolved in water forms a weak acid called carbonic acid.

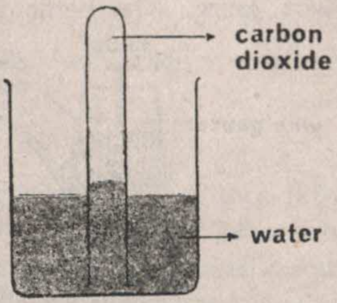


Diagram 70

$$CO_2 + H_2O \rightarrow H_2CO_3$$

(*d*) Bubble carbon dioxide gas into lime water for some time. First you will notice milkiness which disappears after the gas has been bubbled into the liquid for some time. The milkiness is due to the formation of white insoluble particles of calcium carbonate.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

The milkiness disappears due to the formation of calcium bicarbonate which is soluble in water ; a colourless solution is obtained.

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$$

(*e*) Invert another test tube filled with carbon dioxide into a beaker containing the sodium hydroxide solution. Shake the test tube keeping it immersed in the solution. You will notice that the solution of sodium hydroxide rises appreciably into the test tube (diagram 71). Carbon dioxide reacts with sodium hydroxide to form sodium carbonate. With excess of carbon dioxide, sodium bicarbonate will be formed. Since a concentrated solution of sodium hydroxide can be obtained, the solution of the substance is used to absorb carbon dioxide gas.

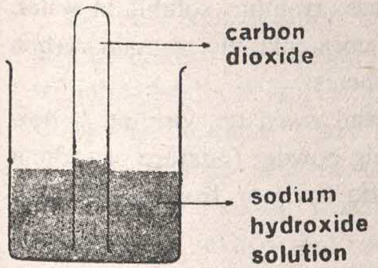


Diagram 71

$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$$
$$Na_2CO_3 + H_2O + CO_2 \rightarrow 2NaHCO_3$$

Both sodium carbonate and bicarbonate are fairly soluble in water.

USES OF CARBON DIOXIDE

(1) *In fire extinguishers.* Carbon dioxide is a heavy gas and does not support burning. This property is useful in fire extinguishers. One type of fire extinguisher is shown in diagram 72.

The extinguisher consists of a metal cylinder containing a bottle enclosed in wire gauze. The bottle is filled with concentrated sulphuric acid and the cylinder contains a saturated solution of sodium bicarbonate filled almost to the top. When the knob is struck on the ground, the bottle breaks. The reaction between the acid and sodium bicarbonate produces carbon dioxide. The pressure of the gas forces a jet of foamy water through the nozzle. Carbon dioxide, being a dense gas, forms a blanket around the fire and cuts off the supply of air to the fire. The foamy water does the extinguishing by cooling the burning material.

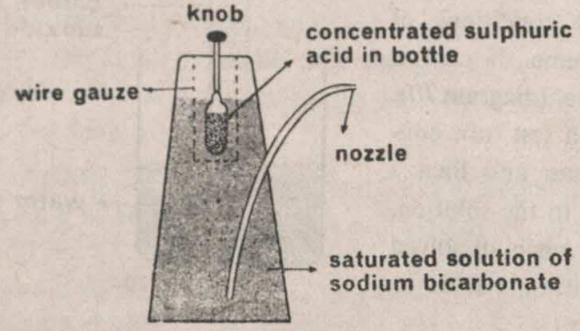

knob
concentrated sulphuric acid in bottle
wire gauze
nozzle
saturated solution of sodium bicarbonate

Diagram 72

This type of fire extinguisher is not safe for putting out electrical fires, because the liquid which comes out of the extinguisher conducts electricity and may cause serious accidents. Modern fire extinguishers contain liquid carbon dioxide which when directed on to a fire cuts off the supply of air as well as cools the burning material.

(2) *In refrigeration.* Solid carbon dioxide, called dry ice, is used as a cooling agent.

(3) *In drinks.* Carbon dioxide under high pressure, is more soluble in water. Its solution in water is called soda water. Lemonade, coca-cola, etc. contain carbon dioxide dissolved under a pressure of about 8 atmospheres.

(4) *In making cakes and bread.* Cakes and bread swell up forming hollow spaces because of carbon dioxide produced from baking powder (mixture of sodium bicarbonate and a weak crystalline acid, e.g. tartaric acid) or from some other substances.

ACTION OF WATER ON SOME ROCKS AND MINERALS

Calcium carbonate occurs in nature as limestone and chalk which are porous to water. During rainfall the carbon dioxide present in air forms a solution of carbonic acid. This reacts with the limestone or chalk present in rocks forming a solution of calcium bicarbonate. Hence, water collected from places which have limestone or chalk deposits contains dissolved calcium bicarbonate. The reaction can be written as follows :

$$CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2$$

Rain water seeping through the soil also dissolves small quantities of various minerals. If this water comes in contact with gypsum, some of the mineral will dissolve because calcium sulphate present in it is slightly soluble in water. Other compounds of calcium and magnesium present in the rocks and minerals will also dissolve in water.

HARD AND SOFT WATER

You must have experienced that sometimes water requires a lot of soap before lather is formed. Such water, usually from a spring or a well, does not lather easily and is said to be ***hard water***. The calcium and magnesium salts dissolved in water cause hardness. Distilled and rain water, which lathers readily with soap, is said to be ***soft water***.

There are two types of hardness in water. ***Temporary hardness***, which can be removed by boiling, is due mainly to the presence of calcium bicarbonate. ***Permanent hardness***, which cannot be removed by boiling, is due mainly to the presence of calcium sulphate.

Activity 4. (*a*) Prepare different samples of water by dissolving calcium bicarbonate and calcium sulphate separately.

(*b*) Prepare a soap solution by dissolving 10 g of soap flakes in 200 cm³ of alcohol and make up this solution to 1 litre by adding distilled water.

(*c*) Place 50 cm³ of each of the solutions into separate conical flasks.

(*d*) Add soap solution from a burette, 1 cm³ at a time, into the conical flask containing water with dissolved calcium bicarbonate (diagram 73). Cork the flask and shake vigorously. Continue adding the soap solution until a lather is formed on vigorous shaking which lasts for a minute. Repeat the experiment with water containing calcium sulphate and note the volume of the soap solution used.

(*e*) Boil each of the two specimens of water for about 15 minutes, allow to cool and repeat the experiment with the soap solution. Tabulate your results as on the next page.

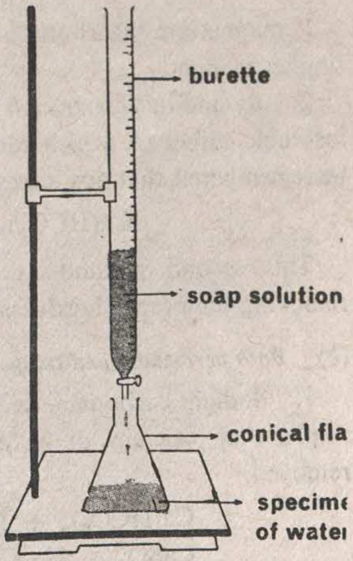


Diagram 73

You will notice that after boiling, the water containing calcium bicarbona requires a smaller amount of soap solution for producing lather. There is difference in the amount of soap solution required with water containing calciu sulphate even after boiling.

Type of water	*Volume of soap solution required*	
	before boiling	*after boiling*
1. Water with calcium bicarbonate 2. Water with calcium sulphate		

It would be interesting to collect water from different sources and compare the degree of hardness in each specimen. Sea water is very hard. Why?

METHODS OF CHANGING HARD WATER INTO SOFT WATER

(*a*) *Temporary hardness*

1. When water containing calcium bicarbonate is boiled, insoluble calcium carbonate is formed which can be removed by filtration or decantation. The decomposition takes place as follows :

$$Ca(HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2$$

If magnesium bicarbonate is present, it will change and form a precipitate in a similar manner.

2. By adding *just enough* amount of slaked lime, all the bicarbonate changes to insoluble carbonate which can be removed by filtration or decantation. It should be remembered that any excess of slaked lime will itself cause hardness.

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$$

This second method is cheaper and therefore preferred to the first for removing temporary hardness.

(*b*) *Both permanent and temporary hardness*

1. Sodium carbonate, i.e. washing soda, reacts with both the bicarbonate and sulphate of calcium or magnesium, forming insoluble carbonate which can be removed.

$$Ca(HCO_3)_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaHCO_3$$
$$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$$

Sodium salts present in water do not cause any hardness because they do not react with soap.

2. *Permutit* is a complex chemical compound which contains sodium ions. The calcium or magnesium ions present in hard water can get attached to the permutit and the sodium ions present in the permutit get dissolved in water

(diagram 74). Thus water becomes free from calcium and magnesium ions.

After a time, there are no sodium ions left in the permutit. Hence it becomes unfit for changing hard water to soft water. The pemutit is "reactivated" by passing a concentrated solution of sodium chloride through the spent permutit.

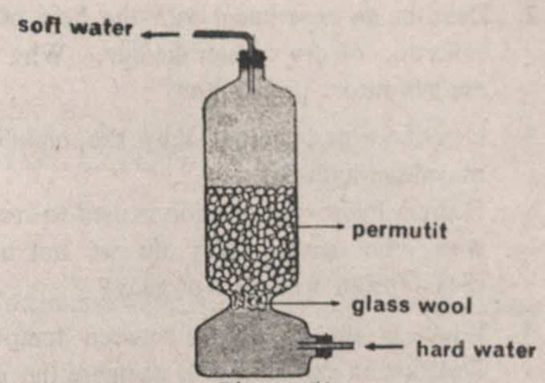


Diagram 74

DISADVANTAGES OF HARD WATER

(*a*) The cleaning action of soap depends upon the formation of lather. A lot of soap is wasted to remove all the calcium and magnesium ions present in hard water as a curdy scum. Modern detergents such as "Surf" or "Det" do not react with calcium and magnesium ions in hard water; hence the problem of soap wastage is less in laundry work, but the problem arises if we have to use hard water for washing our hands and face.

(*b*) When hard water is used in kettles and in boilers, calcium carbonate is deposited as a hard 'fur' inside these. The fur is a bad conductor of heat; hence, the efficiency of boilers or kettles in transferring heat energy is much reduced, leading to wastage. 'Fur' deposits may also lead to bursting of boiler pipes.

ADVANTAGES OF HARD WATER

(*a*) Water is carried to our homes in lead pipes. Soft water can dissolve lead and form the slightly soluble lead hydroxide which is a poisonous substance. Hard water does not dissolve lead. Hence the hardness of water sent to our homes has an advantage.

(*b*) Human bones are composed of calcium phosphate and calcium carbonate. A proper growth of bones is dependent upon the calcium compounds in our diet. When we drink water having a certain degree of hardness, the calcium salts present in water help in the formation of strong bones and teeth.

PROBLEMS

1. How are chalk and limestone hills affected by rain water? What are quicklime, slaked lime and lime water?

2. Describe an experiment with the help of a diagram for the preparation and collection of dry carbon dioxide. Why is dilute sulphuric acid not used in the laboratory preparation?
3. Describe experiments to show the solubility of carbon dioxide in water and in sodium hydroxide.
   Sodium hydroxide solution is used to remove carbon dioxide gas when mixed with other gases. Why do we not use lime water for removing carbon dioxide from a mixture of gases?
4. What is the difference between temporary and permanent hard water? Describe an experiment to compare the degree of temporary and permanent hardness in a sample of water.
5. What are the disadvantages of hard water? Is hard water unfit for drinking purposes?
6. Describe methods for the removal of both types of hardness of water in one single process.

11

Acids and their Salts

In this chapter we shall study the preparation and properties of some acids and their salts.

HYDROGEN CHLORIDE GAS

Activity 1. Add dilute sulphuric acid to sodium chloride taken in a test tube. Do you notice any effervescence ? In another test tube put a small amount of sodium chloride and add concentrated sulphuric acid. Is any gas evolved ? Repeat the experiments using calcium chloride and potassium chloride.

You will notice that there is no apparent reaction of dilute sulphuric acid on the chlorides. A vigorous reaction is noticed when concentrated sulphuric acid reacts with a chloride. If you blow across the top of the test tube, you will observe a gas given out which fumes in air. This gas is hydrogen chloride gas.

Sulphuric acid is a non-volatile acid and reacts with chlorides to form the volatile hydrogen chloride.

Activity 2. Place some sodium chloride in a flask and add concentrated sulphuric acid. Warm gently on a sand bath. Since the gas is heavier than air, it is

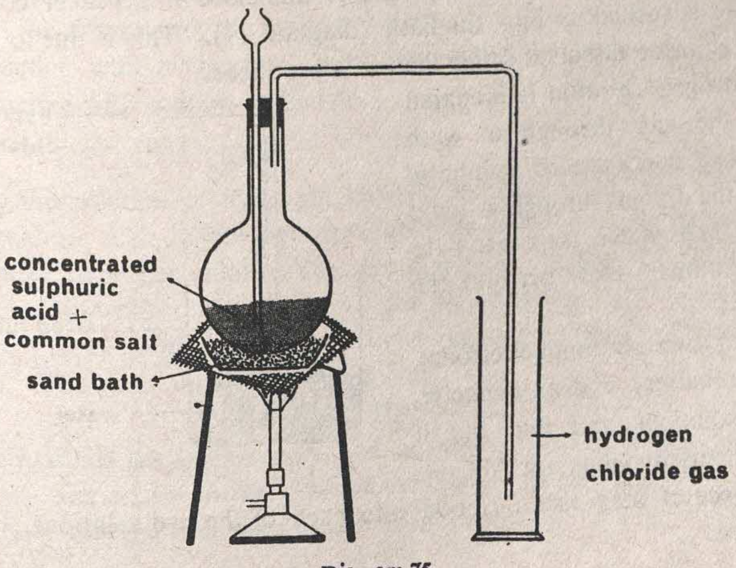


Diagram 75

collected by upward displacement of air (diagram 75). The solution left in the flask. contains sodium bisulphate.

$$NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$$

Fill a flask also by displacing its air as you do in the case of gas jars. Fit the flask with a cork carrying a glass tube whose one end is drawn into a jet.

PROPERTIES OF HYDROGEN CHLORIDE

Activity 3. (*a*) Note the colour of the gas and take its smell from a short distance away very cautiously.

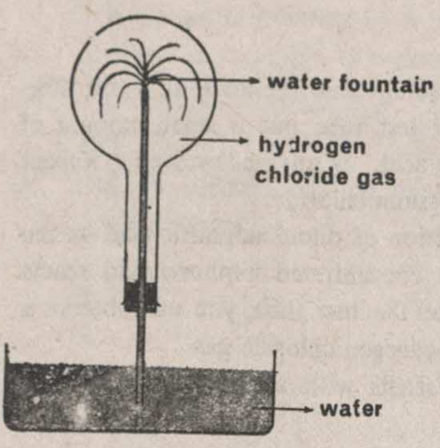


Diagram 76

(*b*) Invert the flask containing the gas in a trough containing water. The water first rises slowly and when a few drops of water have entered the flask, a fountain starts to play at the mouth of the jet (diagram 76). This "fountain experiment" shows the extreme solubility of hydrogen chloride in water. If a few drops of blue litmus are added to the resultant solution, the litmus turns red showing that an acidic solution is formed.

A saturated solution of hydrogen chloride is formed by connecting the delivery tube to an inverted funnel whose rim just dips in water. If the delivery tube is immersed in a beaker containing water, the liquid is sucked up into the flask (diagram 77). This is due to the fact that hydrogen chloride dissolves faster than it is produced.

(*c*) Dry hydrogen chloride is prepared by bubbling the gas through a wash bottle containing concentrated sulphuric acid. Bubble the dry gas through a liquid called ***acetone***, and water, separately to obtain two solutions. Now perform the following tests :

(*i*) Introduce two platinum electrodes, connected to a battery and an ammeter, into the two solutions, and find out if they conduct electricity (diagram 78).

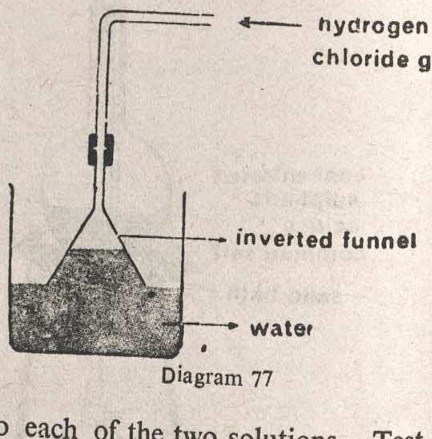


Diagram 77

(*ii*) Put a piece of magnesium ribbon into each of the two solutions. Test for any gas liberated.

(*iii*) To each solution of hydrogen chloride in acetone and in water, add solid anhydrous sodium . Is carbon dioxide liberated in both the cases ?

(*iv*) Put a dry blue litmus paper in the solutions and notice any change of colour.

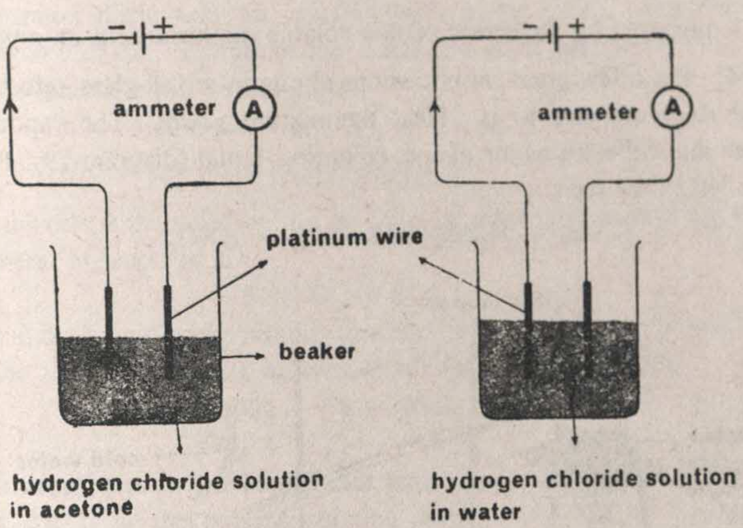

ammeter
A
ammeter
A
platinum wire
beaker
hydrogen chloride solution in acetone
hydrogen chloride solution in water

Diagram 78

The solution of hydrogen chloride in acetone does not produce hydrogen when magnesium ribbon is added to it, and does not react with sodium carbonate; nor does it conduct electricity. The litmus paper remains unchanged in this solution.

On the other hand, the aqueous solution conducts electricity, produces hydrogen on reacting with magnesium, turns blue litmus red, and liberates carbon dioxide on reacting with sodium carbonate.

THE HYDRONIUM ION

Thus, the solution of hydrogen chloride in water is an acid. This acid is called hydrochloric acid. Since hydrogen chloride solution in acetone does not conduct electricity, hydrogen chloride does not appear to contain ions which are responsible for the conduction of electricity. As water is also a non-conductor, it would appear that the ions are produced by a reaction between hydrogen chloride and water. The reaction is as follows :

$$HCl + H_2O \rightarrow H_3O^+ + 3Cl^-$$

H_3O^+ is called the ***hydronium ion*** and for simplicity it is taken as H^+, i. e. a hydrogen ion. *The acid is therefore a compound which produces hydrogen inos as the only positively charged ions when dissolved in water.*

It is interesting to note that *the charge on an ion is equal to the valency of the element or radical. Hydrogen and metallic substances carry positive charges while non-metallic substances carry negative charges*. e. g. Na^+, Ca^{2+}, Al^{3+}, OH^-, SO_4^{2-}, PO_4^{3-}.

NITRIC ACID

Nitric acid is prepared by the action of non-volatile sulphuric acid on any nitrate.

Activity 4. Put a few grams of potassium nitrate in an all-glass retort and add concentrated sulphuric acid to it. Heat the mixture ***gently***. The vapour of the acid is cooled and collected as an almost colourless liquid (diagram 79). Potassium bisulphate is left in the flask.

$$KNO_3 + H_2SO_4 \rightarrow KHSO_4 + HNO_3$$

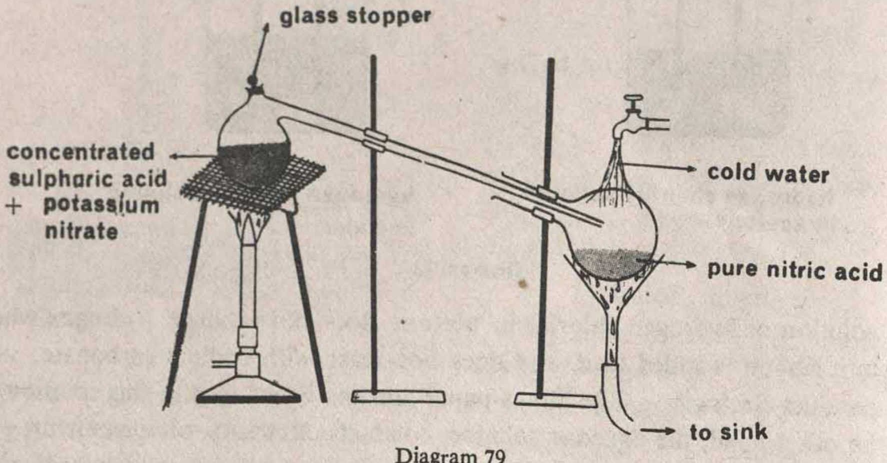


Diagram 79

Nitric acid thus obtained is slightly yellow because of slight decomposition of the acid due to heating when brown fumes of nitrogen dioxide are given out which dissolve in the acid. You might have seen the brown fumes in bottles of concentrated nitric acid kept in your laboratory. Gentle heating is essential in the preparation of the acid. Since nitric acid fumes attack rubber, an all-glass apparatus must be used.

PROPERTIES OF NITRIC ACID

In its reaction with bases, carbonates and bicarbonates, nitric acid behaves like other acids. But its reaction on metals is very different.

(*a*) Cold and very dilute nitric acid (about 5 per cent) reacts with magnesium to give hydrogen.

$$Mg + 2HNO_3 \rightarrow Mg\,(NO_3)_2 + H_2$$

(*b*) Dilute nitric acid reacting with most metals produces a colourless gas which on coming in contact with air gives brown fumes of nitrogen dioxide. This colourless gas is called nitrogen monoxide. Other products are nitrate of the metal and water. For example, with copper the reaction is as follows :

$$3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$$

(*c*) Concentrated nitric acid on reacting with most metals produces brown fumes of nitrogen dioxide. Nitrate of the metal and water are the other products. With copper the reaction will be as follows:

$$Cu + 4HNO_3 \rightarrow Cu(NO_3)_2 + 2H_2O + 2NO_2$$

SULPHURIC ACID (THE CONTACT PROCESS)

First sulphur dioxide is prepared by the burning of sulphur or by heating strongly a sulphide mineral in excess of air.

$$S + O_2 \rightarrow SO_2$$

If sulphur dioxide molecules could combine with oxygen, they would form sulphur trioxide which on reacting with water will form sulphuric acid.

$$2SO_2 + O_2 \rightarrow 2SO_3$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$

The combination between sulphur dioxide and oxygen takes place at a temperature of about 450°C in the presence of fine particles of platinum deposited on asbestos wool (diagram 80). Platinum acts as a ***catalyst***. Vanadium pentoxide is another catalyst now being used widely because it is cheaper and more efficient than platinised asbestos.

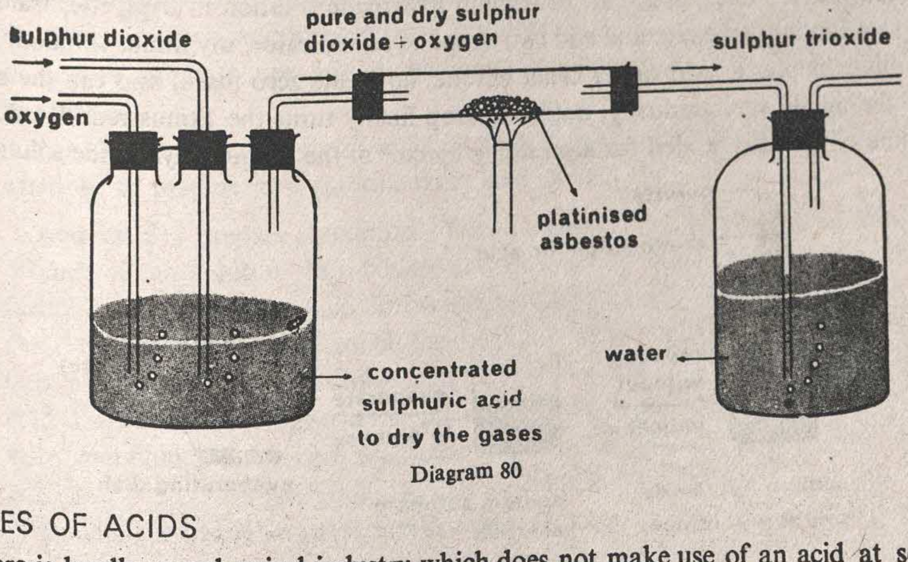

sulphur dioxide
oxygen
pure and dry sulphur dioxide + oxygen
sulphur trioxide
platinised asbestos
water
concentrated sulphuric acid to dry the gases

Diagram 80

USES OF ACIDS

There is hardly any chemical industry which does not make use of an acid at some stage or the other. You will have used these acids in the laboratory and outside, and will be using them a lot in future.

Large quantities of hydrochloric acid are used for the manufacture of chlorine gas, which has a vast application. You will have used this acid in the preparation of gases like hydrogen and carbon dioxide. The acid is used for cleaning iron which is then galvanised to check rusting.

Nitric acid is used in the manufacture of dyes, drugs, synthetic fibres and plastics. It finds important use in the making of fertilisers like ammonium nitrate. Explosives like nitrocellulose and T.N.T. are made from nitric acid.

Sulphuric acid is the backbone of chemical industries, so much so that the chemical wealth of a nation is said to be measured by how much sulphuric acid the nation uses. It is used in the manufacture of fertilisers like ammonium sulphate and superphosphate of lime. It is used in preparing other acids, in refining of petroleum, in the preparation of detergents, synthetic fibres and pigments, etc.

SALTS OF ACIDS

There are several ways of preparing salts. Some of the commonly used methods are given below.

(1) To prepare a soluble salt by the action of an acid on a soluble oxide, hydroxide, carbonate or a bicarbonate; for example, to prepare sodium sulphate by reacting sodium hydroxide with sulphuric acid.

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$$

Activity 5. Prepare solutions of sodium hydroxide and sulphuric acid in distilled water. Suck in 25 cm^3 of sodium hydroxide solution in a pipette, transfer this solution into a beaker and add two drops of an indicator, say litmus solution. Fill the dilute sulphuric acid into a clean burette, up to the zero mark, and run the acid into the alkali, very gradually, until one drop finally turns the litmus red. Read the volume of the acid needed for ***neutralising*** 25 cm^3 of the sodium hydroxide solution.

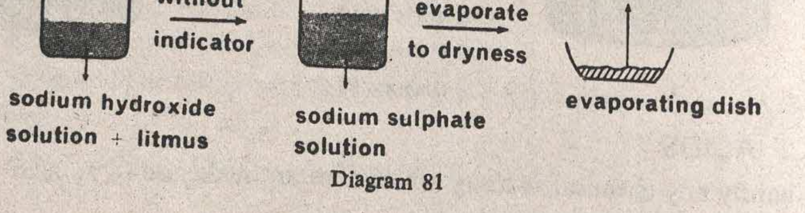


Diagram 81

Take another 25 cm^3 of the sodium hydroxide solution in an evaporating dish and add the same volume of sulphuric acid as found in the above experiment, this time without the indicator. Evaporate the solution until crystals start to appear and a saturated solution is obtained. More crystals appear on cooling; extract the crystals, wash with a small amount of cold distilled water and dry between blotting paper sheets. This process is called crystallisation from the solution.

(2) To prepare a soluble salt by the action of an acid on an insoluble oxide, hydroxide or a carbonate; for example, to prepare copper sulphate from copper oxide.

$$CuO + H_2SO_4 \rightarrow CuSO_4 + H_2O$$

Activity 6. Take about 50 cm^3 of dilute sulphuric acid in a beaker and heat on a wire gauze. Add black copper oxide, a little at a time, with constant stirring. Add the oxide until it is in excess when some of the oxide will settle at the bottom. The acid is completely used up. Filter off the excess oxide. The filtrate will be a blue solution of copper sulphate. Now obtain crystals of copper sulphate as in the first method.

(3) To prepare a soluble salt by the action of an acid on a metal; for example, to prepare zinc sulphate by the action of dilute sulphuric acid on zinc.

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$$

Activity 7. Take about 50 cm^3 of dilute sulphuric acid and warm it. Add small pieces of zinc, a little at a time, with constant stirring. You will observe effervescence because of the evolution of hydrogen gas. Add till the metal is in excess and some of the metal settles at the bottom. Filter off the metal and collect the filtrate in an evaporating dish. Crystallise as in the first method. If a few drops of copper sulphate are added the reaction between zinc and sulphuric acid is accelerated.

(4) To prepare an insoluble salt by a double decomposition reaction. For example, to prepare lead chloride from lead nitrate.

Activity 8. Prepare a solution of lead nitrate in distilled water. Take about 50 cm^3 of this solution in a beaker and slowly add dilute hydrochloric acid, until further addition of the acid forms no precipitate. The heavy precipitate of lead chloride settles at the bottom of the beaker. Filter to get the precipitate on the filter paper. Wash the insoluble lead chloride on the filter paper several times with cold distilled water to remove the excess of the acid sticking to the precipitate. Cold water and cold solutions are used because lead chloride is soluble in hot water.

$$Pb(NO_3)_2 + 2HCl \rightarrow PbCl_2 + 2HNO_3$$

In case the insoluble substance does not dissolve on heating, warm solutions are used in the precipitation and hot water is used in washing the precipitate.

(5) *Synthesis*. Some salts, such as ferric (iron III) chloride or ferrous (iron II) sulphide, are prepared by combining the elements present in the salts.

$$2Fe + 3Cl_2 \rightarrow 2FeCl_3$$
$$Fe + S \rightarrow FeS$$

SOLUBILITY OF COMPOUNDS

The following list gives the solubility of various compounds.

(1) Soluble compounds are :
  (*a*) All nitrates, bicarbonates; all sodium, potassium and ammonium salts.
  (*b*) All chlorides except those of silver and lead. Lead chloride is, however, soluble in hot water.
  (*c*) All sulphates except those of lead, barium and calcium. Calcium sulphate is, however, slightly soluble.

(2) Insoluble compounds are :
  (*a*) All oxides except those of sodium, potassium.
  (*b*) All hydroxides except those of sodium, potassium and ammonium. Calcium, magnesium, barium and lead hydroxides are slightly soluble.
  (*c*) All carbonates except those of sodium, potassium and ammonium.

PROBLEMS

1. Describe an experiment to show that hydrogen chloride gas is extremely soluble in water. Why is the gas not dissolved by dipping the delivery tube in a beaker containing water?
2. Describe experiments to show that when hydrogen chloride is dissolved in water an acid is formed, and no acid is formed when the gas is dissolved in any other solvent.
   How do these experiments help us to define an acid?
3. How is nitric acid different from other acids in respect of its action on metals? In what respect is it similar?
4. Why is concentrated sulphuric acid used in the laboratory preparation of nitric acid? Can concentrated hydrochloric acid be used instead?
5. Why is concentrated nitric acid in the laboratory sometimes pale yellow, although pure nitric acid is colourless?
   How can salts be obtained from nitric acid? Give examples.
6. How is sulphuric acid prepared by the contact process? Why is this acid called the backbone of chemical industries?

12

The Human Body

One of the most striking facts about living beings is that they obey the same laws of physics and undergo the same types of chemical reactions as take place among the non-living materials. Living organisms, whether an animal or a plant, are made up of the elements such as carbon, oxygen, nitrogen and hydrogen. While a car uses the chemical energy stored in petrol for its locomotion, we obtain the necessary energy for our activities from the food we eat. The eye, which is an organ of a living being, is similar to a camera in many respects.

Yet, no one will describe a car or a rock as a living being. There is something special about the living. Some of the special characteristics of the living which we have studied before are (*a*) growth, (*b*) feeding, (*c*) excretion (*d*) sensitivity, (*e*) movement and (*f*) reproduction. These characteristics are useful for the survival of the living beings and their future progeny.

MAN AS A MAMMAL

The one example of a living being we shall study in greater detail in the following chapters is man. The entire living world can be classified into two kingdoms : animal and plant. The animal kingdom consists of two main groups: (a) the non-vertebrates, i.e. animals without backbone, and (b) the vertebrates.

The five chief classes of vertebrates are (*i*) fish, which include eel and the shark; (*ii*) amphibians such as the frog, toad and the newt; (*iii*) reptiles such as grass-snake, tortoise and lizard; (*iv*) birds, which include penguin, ostrich and duck; and (*v*) mammals such as whale, dog, kangaroo, monkey and man.

While animals have many common features, there are also significant differences. An insect has six legs while man has four ***limbs***. Mammals have hairs to keep them warm while birds have feathers which serve the same purpose. Even among mammals there are differences. Most mammals have a tail and they are hairy but man has a naked skin and lacks a tail. Many animals stand on their four limbs; man stands on two limbs. However, apart from these superficial differences, there is much in common amongst the mammals particularly in terms of the functions of various bodily organs.

(*a*) In mammals, ordinarily, the body is maintained at a constant temperature; mammals are therefore called warm-blooded animals.

(*b*) A mammal has a large brain and shows ability to learn from past experience and act intelligently; in this process it shows a complex behaviour.

(*c*) The teeth of mammals are differentiated into various types and have specialised functions. They enable different kinds of food to be eaten.

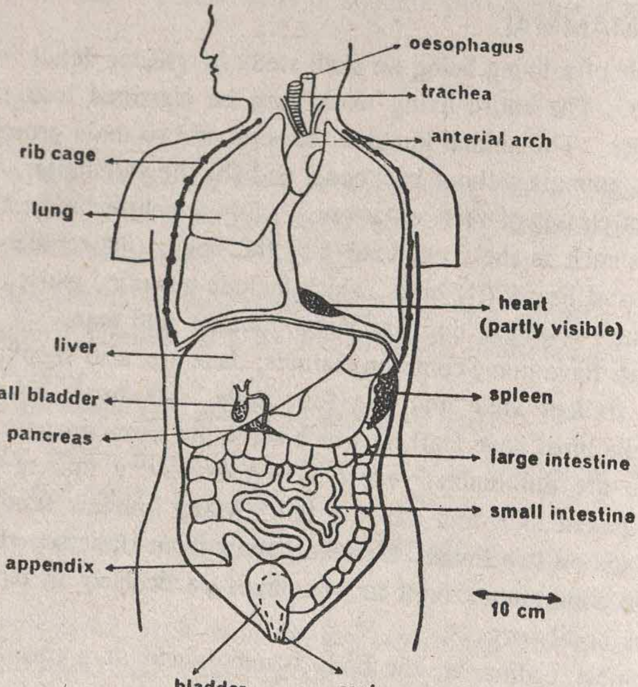
(*d*) The heart of mammals consists of four chambers which enable the blood going to the lungs and that going to the body to be kept separate.

(*e*) The female mammals retain the fertilized egg within their body where it is protected and supplied with food and oxygen during its growth. After birth as a young baby, the young progeny is fed on mother's milk.

Over the past millions of years since life first appeared on the earth, man has gradually come to dominate the living world. This advance has been made most rapid during the past 20,000 years. His ability to communicate, to store information, and to pass knowledge and experience from one generation to the next has been of tremendous advantage. For example, the discovery of penicillin made in one part of the world became common knowledge within a generation. Other remarkable examples of spread and use of knowledge are wireless, synthetic fibres and "atomic energy".

ORGANS AND SYSTEMS

As studied earlier, a cell is the smallest unit of function of all living organisms.



The general contents of the thorax and abdomen (excluding the reproductive organs)

Diagram 82

A number of these cells having similar structure and function form a group called the tissue. Several tissues work in combination in our body in an organ. Diagram 82 shows the position of some of these organs in the human body.

The body of an animal consists of a number of organs; each organ such as the heart, lungs, stomach, etc. does a particular job for our body. For example, the heart is a pump which maintains a certain amount of blood pressure so that it can flow through the body. The ***arteries*** and the veins are other organs which enable the blood to be transported. Thus, some organs work in cooperation for a particular purpose; they form a ***system.*** The heart, arteries and the veins form the circulatory or transport system. Some of the important systems in the human body, and their chief functions, are given in the following table :

System	*Function*
1. Skeletal	support and movement
2. Muscular	support and movement
3. Circulatory	transport of materials round the body
4. Respiratory	obtaining energy for growth and activity
5. Digestive	nutrition
6. Nervous	receiving stimulus and carrying messages
7. Endocrine	carrying messages for control of growth etc.
8. Excretory	removal of useless or harmful matter
9. Reproductive	to ensure that a new generation is produced

In some ways therefore the human body resembles a factory. In a factory, different individuals are involved in different tasks. Some are doing the same type of task in a group. There may be more than one such group in a particular department. The several departments work in cooperation. In the human body, the nervous system is responsible for the coordination of the total human activity ; the control of this is in the brain. Raw materials are required for a factory. These are processed as they travel from one department to another. In the end finished goods and waste are produced. All this requires energy in some form. The food that we eat is also processed. The waste is thrown out while the useful part utilised for growth and other activity.

THE SKELETON

Large animals and plants cannot support themselves unless they have some rigid tissues which make up their frame. Trees are provided with such a rigid material in the form of xylem vessels. In the vertebrates, the bones make up for this stiffness. The skeleton also provides protection for vital parts and aids movement.

The skeleton system made up of 208 bones and the muscular system together enable the various movements in man. When a person walks or talks, he is moving bones and muscles. The 208 bones in the human skeleton make up the head, trunk and the limbs (diagram 83). The bones represent about 20 per cent of the total weight of the human body.

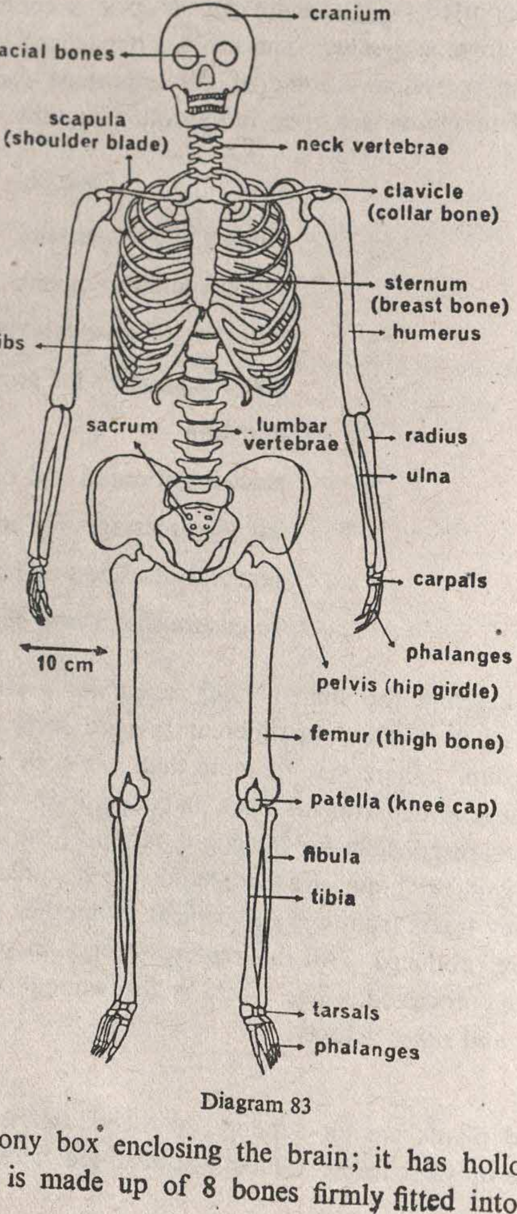


Diagram 83

The ***cranium*** is a bony box enclosing the brain; it has hollows for lodging the eye balls, ears, etc. It is made up of 8 bones firmly fitted into each other: The face has 14 bones of which 13 are joined together to the bones of the head. Only the lower jaw bone is mobile.

The ***vertebral*** column (diagram 84) is the main support of the skeleton. It contains 33 bones and also protects the ***spinal cord,*** a vital part of the central nervous system.

The first neck or ***cervical*** vertebra supports the head and is called the ***atlas.*** The atlas together with the skull moves round a projection on the second vertebra, called the ***axis.*** There are 12 pairs of ***ribs*** which are joined to the ***thoracic*** vertebrae at the back. In the front of this rib cage is the breast bone, ***sternum.*** The first 7 pairs of ribs are joined to the sternum through ***cartilages*** (diagram 85). The cartilages are tissues which are softer than bone but harder than muscle.

The next 3 rib pairs are joined to each other by their cartilages. The last two pairs are not joined to the sternum at all and are called ***floating ribs.***

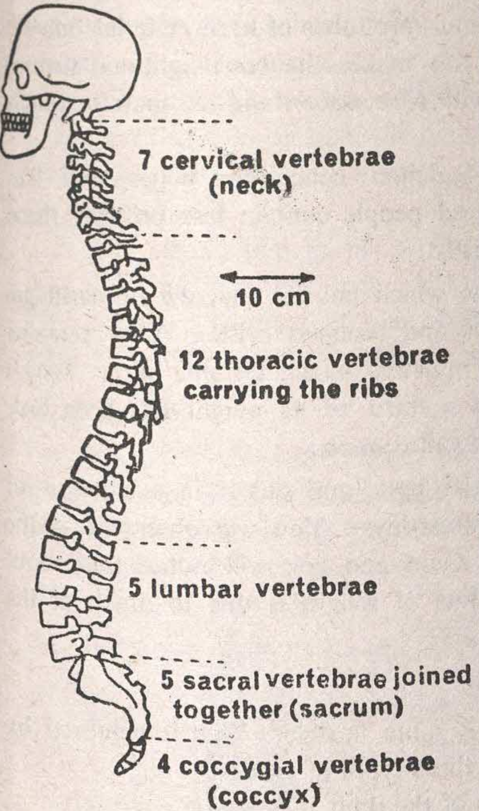


Diagram 84

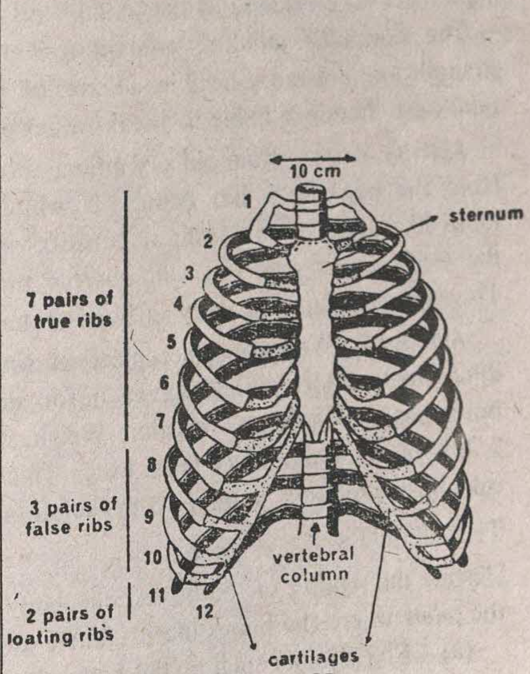


Diagram 85

THE LIMBS

The limbs are organs of locomotion attached to the trunk. They enable an animal to go in search of food, or to escape from danger. The upper and lower limbs in human beings show marked similarity in structure. Each is supported from the trunk by a ***girdle***. The upper limbs hang from the ***pectoral*** (shoulder) girdle while the lower limbs support the trunk through the ***pelvic*** (hip) girdle.

THE BONES

A bone may seem inert but it is a living material nourished by the blood. Most of the bones first appear as cartilage. They grow in childhood and youth for which vitamin D is essential. They can also become diseased. Bones also exhibit the property of repair if one is broken in an accident.

The skeleton is made up of a variety of bones. The femur is the longest bone (diagram 83); the humerus, radius and ulma are also long. There are a number of short bones such as the knee-cap, carpals, tarsals and vertebrae.

Bones are made up of 85 per cent of calcium phosphate and about 9 per cent calcium carbonate. Thus calcium and phosphorous are the most important elements. The large bones such as the femur are tubes of hard material outside with partitions of spongy material inside; this makes the bone light and strong. The spongy light material has spaces filled with ***bone marrow*** and red marrow which makes the ***red corpuscles*** of the blood.

The bones of children contain less of calcium; hence, the bones have less strength and are more flexible. Bones of aged people contain less protein; these bones are therefore liable to break rather easily.

Activity 1. Weigh an old dry animal bone which has no marrow or cartilage. Hold the bone in a hot flame. It whitens and becomes brittle. What remains looks like wood or coal ash; it consists of minerals which do not burn. Weigh the bone again and you will observe that a third of its weight has been lost. This is due to burning away of bone protein called ***ossein***.

Activity 2. Weigh another piece of similar bone and put it in a solution of dilute hydrochloric acid. Leave it for several days. You will observe that the bone becomes soft and elastic. Weigh it again and you will notice that about 2/3rd of its weight has been lost. This loss of weight is due to much of the calcium compounds going into the solution.

THE JOINTS

Despite the rigidity of the bones, our body is quite flexible. This is achieved by the ***joints*** where the bones meet. There are three types of joints :

(a) Fixed joints such as the bony plates of the skull.

(b) Semi-mobile joints which allow only a small amount of movement. An example is the non-sliding joints of the vertebrae.

(c) Mobile joints which allow considerable movement, i.e., the elbow, shoulder, knee and hip joints.

In the mobile joints, the bones are attached to each other by a surrounding tough capsule made of ligaments. One of the bones has cavity into which the head of the other bone fits (diagram 86). The two surfaces which are in contact are covered with soft cartilage to prevent friction and to break shock. The cartilages are lubricated with a thick liquid called the ***synovial fluid.***

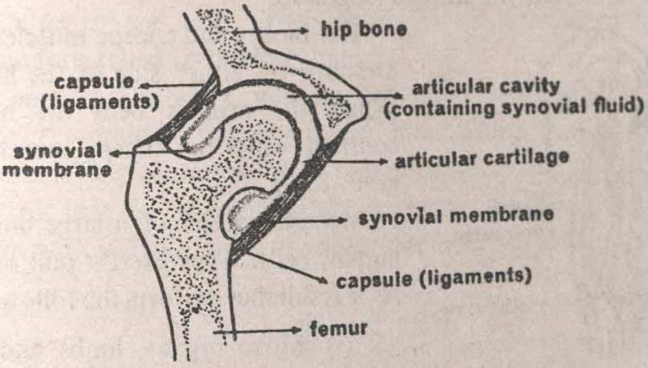


Diagram 86

The cartilages which bind the bones together at a joint are usually very tough; these make the joints very strong. Bones therefore get broken more oftener than the dislocation of joints.

A very strong pull in the wrong direction can overstretch the ligaments of a joint and sometimes tear them. If the bone is not pulled out of the joint, there may only be a sprain. If one of the bones moves out of the joint a **dislocation** occurs. In both cases there may be an increase of the synovial fluid.

MUSCLES

The muscular system, along with the skeletal system, is associated with movement. These muscles contract in length to exert a pull; this causes movement of the bone to which it is attached, or squeezes a liquid such as blood.

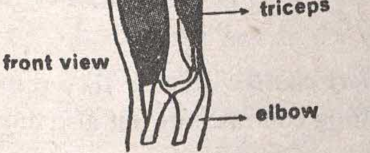


Diagram 87 (*a*)

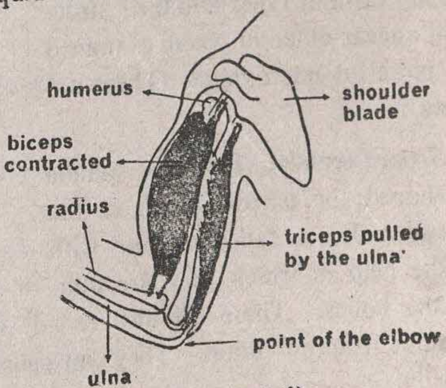


Diagram 87 (*b*)

Activity 3. With your right hand, grip the muscle in your left upper arm. Now bend the arm. You will feel the contraction of the muscle. Straighten the arm and you will observe that the muscle lengthens.

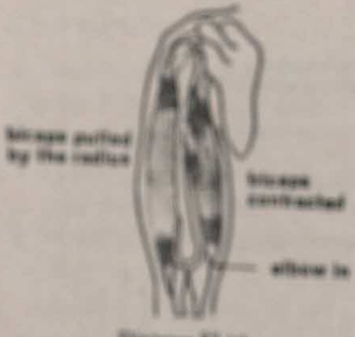


Diagram 87 (b)

The biceps and triceps muscles of the upper arm are on either side of the humerus bone. When the arm is bent the biceps muscles contract while the triceps muscles relax (diagram 87 b).

Muscles consist of a large number of long narrow cells. They exert a pull on contraction. As a result they perform the following functions:

(i) Move organs, limbs and hairs in the skin.

(ii) Force a liquid through various transport tubes in our body.

(iii) Maintain balance and correct posture by holding structures in position.

You will have noticed that a person who falls asleep standing up would lose his balance and fall. People who doze in a chair tend to slump forward or sideways. This happens because during sleep the muscles responsible for posture relax because the nervous system does not act on them. Thus, bodily balance is due to the coordinated contraction of certain muscles. These particular muscles are *striped* in their structure.

Activity 4. To show the elasticity of a muscle, take a striped muscle of a frog and set up the apparatus as in diagram 88. Measure the original and final length of the muscle when different weights are placed in the pan. What happens when the weights are removed ?

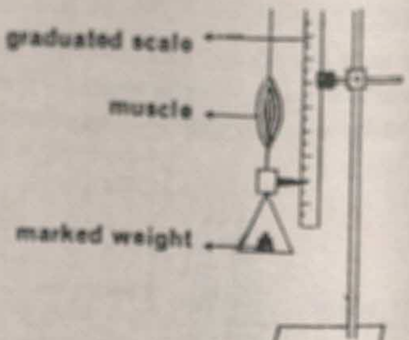


Diagram 88

Muscles are all not of the same type. Muscles are of three types and their structures will appear different when examined under a powerful microscope. These are as follows :

(a) *Striped muscles.* These are spindle shaped; the narrow bands at the two ends are called ***tendons***, with the help of which they are attached to the bones. These are also called ***voluntary muscles*** because they respond to a stimulus from our brain. They can cause strong contractions but also tire out rather easily.

(*b*) *Plain or smooth muscles.* These muscles form the wall of the intestine and the blood vessels, etc. They contract slowly but can remain in such a position for a long time. Their action is not controlled by the will and are therefore called involuntary muscles.

(*c*) *Heart muscle.* The heart muscles are also involuntary in action. They contract rhythmically throughout our life. These muscles are of a special structure. They require a lot of energy to carry out their function. It is estimated that in a normal human being the heart does work which requires almost 1500 joules of energy per hour, or about ½ watt power.

PROBLEMS

1. Explain three functions of bones in the human body.
2. What are the main salts present in the bone ? What parts of our diet would especially assist bone formation ?
3. How can one explain the fact that bones in our body are living parts ?
4. Explain how the human body is kept upright by muscles and bones.
5. What is a cartilage ? How does it differ from a bone and a muscle ? Where in our body are the cartilages placed ?
6. What are joints ? What prevents the bones from coming apart ? How are the joints lubricated ?
7. With the help of a diagram explain how muscles enable us to lift our arm. Which muscles are involved in this action ?
8. Compare the structure of striped and smooth muscles. How do these differ in their function ?
9. What is a major advantage of a backbone made up of vertebrae over a solid backbone ?
10. Give names appropriate to the following structures in a mammal :
    - (*a*) two muscles in the forelimb.
    - (*b*) a cord joining muscle to bone.
    - (*c*) three long bones in the forelimb.
    - (*d*) a bone which supports the skull.
    - (*e*) two bones which form the shoulder joint.

13

The Circulatory System

A small animal such as an amoeba receives substances directly into every part of the body from the environment: For larger animals it is not possible for all parts of the body to receive useful materials directly from the environment, or to remove harmful wastes away from these deeply buried parts directly to the environment. There is thus need for a ***transport system*** within our bodies by which this exchange of materials can take place. The ***circulatory system*** provides the path to and from all the cells in our bodies. Its functions are as follows :

(*a*) Distribution of oxygen and soluble food substances made available by digestion and absorption.

(*b*) The removal of wastes such as carbon dioxide and urea.

(*c*) The distribution of hormones and other special chemicals for reasons of coordination of the bodily functions.

(*d*) The dissipation of heat energy from where it is generated to where it is needed, and its removal.

The circulatory system consists of the following organs : (*i*) the heart, which is a muscular pump for propelling the blood; (*ii*) ***arteries***, which carry the blood away from the heart to other parts of the body; (*iii*) ***capillaries***, which bring the blood in contact with the cells of our body; and (*iv*) ***veins***, which carry the blood back to the heart (diagram 89).

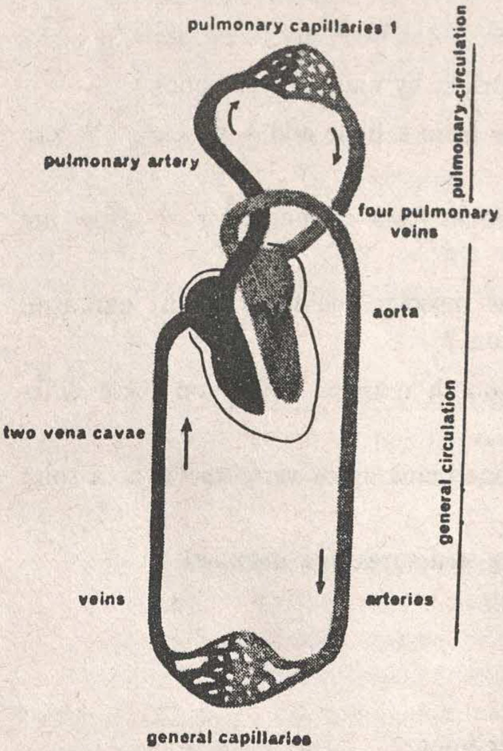


Diagram 89

THE HEART

The heart weighs about 300 grams and is about the size of your clenched fist (diagram 90). It lies between the two lungs in the rib cage. It is a double pump made of only muscles, and consists of

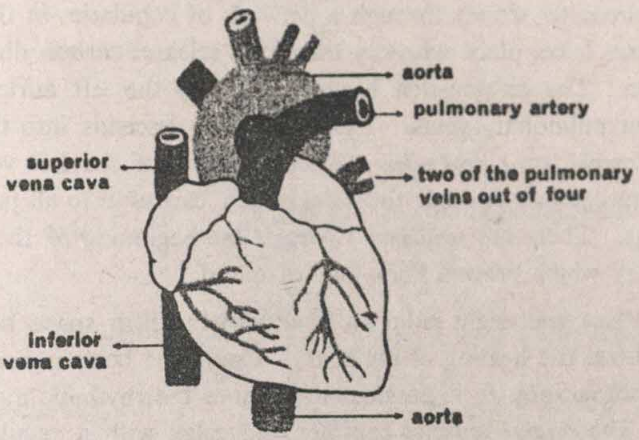


Diagram 90

4 cavities. The ***auricles*** are the upper chambers of the two pumps and have thin muscular walls. The two ***ventricles*** are the lower chambers made of thick muscular walls. The auricles are the inflow chambers and the ventricles are the outflow chambers of blood (diagram 91).

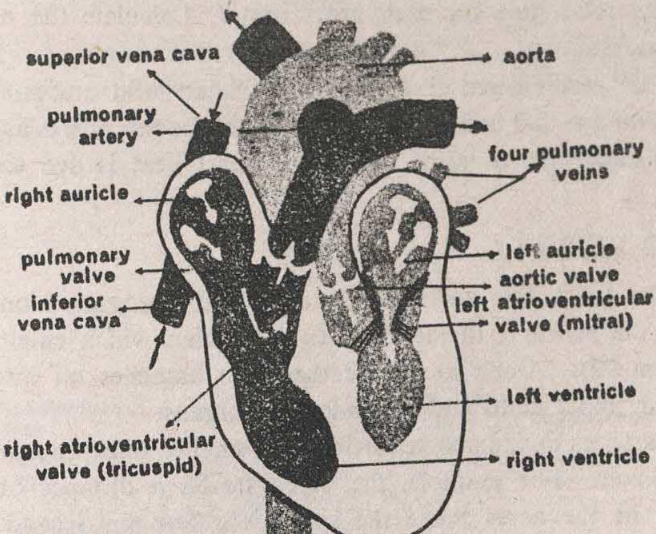


Diagram 91

Blood from the body comes into the right auricle through the two ***vena cavae***, passes into the right ventricle, and is then squeezed through the ***pulmonary artery*** into the lungs. This is achieved by the contraction of the auricle and the ventricle, and the tricuspid ***valve*** between them which enables the blood to flow in one direction only.

The blood circulates slowly through a network of capillaries in the lungs. Here exchange of gases takes place whereby the blood releases carbon dioxide and takes in fresh oxygen. The oxygen-rich blood returns to the left auricle of the heart through the four pulmonary veins. The blood then descends into the left ventricle through the *bicuspid* or *mitral valve*. A contraction of the left ventricle enables the blood to squeeze out through the *aorta* which carries it to all parts of the body except the lungs. There are *semilunar* valves at the beginning of the aorta and the pulmonary artery which prevent back flow of blood.

Activity 1. Place your right palm on level with the fifth space between the left ribs. You will feel the beating of the heart. Count the beats in one minute.

By X-ray photography it is possible to observe the rhythmic movements of the human heart. The *cardiac* muscles contract and relax with a regular rhythm and cause the following sequence in a normal heart :

contraction of the auricles	0.1 second
contraction of the ventricles	0.3 second
a period of rest before the cycle repeats	0.4 second

What is the total time for each heart beat ? Calculate the number of heart beats in one minute.

It should be remembered that the rate of heart beat varies from person to person, and with age and activity. For some athletes the rate is as low as 60 per minute. The sound that is heard during the heart beat is due to closing of the valves.

THE BLOOD VESSELS

On leaving the heart, the aorta bends over and descends along the vertebral column. At the *pelvis*, it divides into two branches which enter the two lower limbs (diagram 92). Along its course the aorta branches off into arteries which reach the head, upper limbs and the abdominal organs.

The main arteries divide and subdivide into smaller ones into which the blood flows more slowly. For example, the blood travels a distance of almost 50 cm every second in the aorta while the speed is a few mm/second in the smaller arteries. In the thinnest vessels called the capillaries the blood flows at the very slow speed of about 1 mm/second. The capillaries form a very close network all over the body. The capillaries carry the oxygenated blood to the individual cells and tissues. The exchange of oxygen, carbon dioxide, food and waste products takes place between these tissues and the capillaries.

After having passed through all parts of the body organs, the tiny capillaries converge to form larger vessels called the **veins**. The veins become larger and

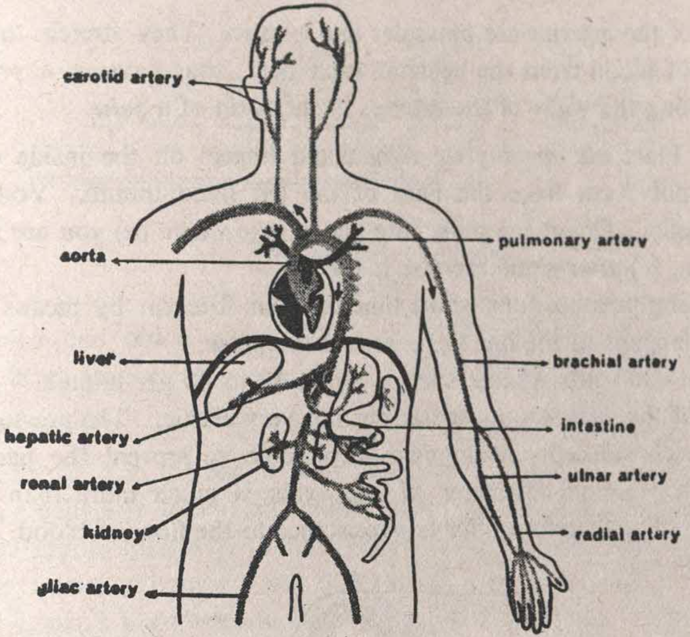


Diagram 92

larger and carry the blood to the heart (diagram 93). The experimental work and conclusion on the flow of blood through the vessels to and from the heart was first presented by William Harvey in 1628.

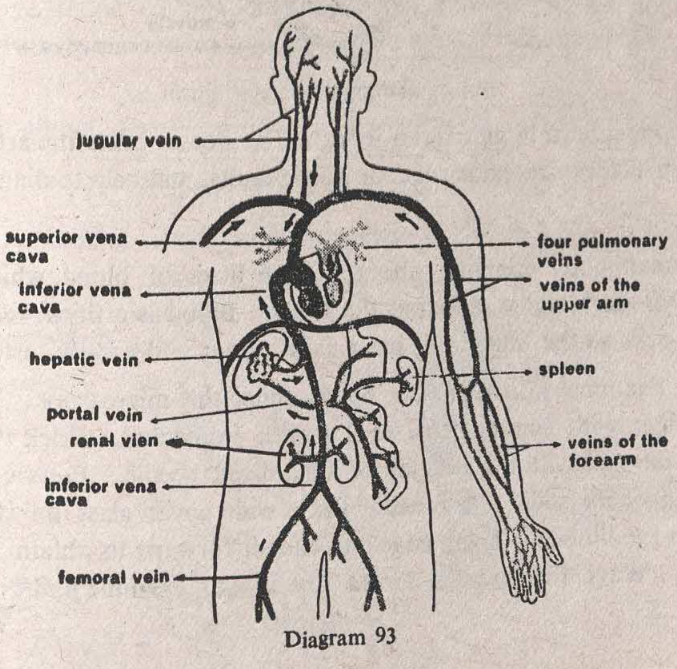


Diagram 93

The walls of the arteries are muscular and elastic. They stretch to receive the large volume of blood from the heart at each beat, thus causing a pressure wave that travels along the walls of the arteries in the form of a ***pulse.***

Activity 2. Place the tip of your right hand fingers on the inside of your left hand wrist about 5 cm from the base of the left hand thumb. You will feel a pulse periodically. Count the pulse rate per minute when (*a*) you are standing up, (*b*) lying down, (*c*) after some exercise is taken.

Exert a strong pressure for a short time on your forearm by means of a scarf. Notice what happens to the hand and record the pulse.

The normal adult rate when resting is about 60 to 80 per minute.

The walls of the veins are muscular but not very elastic. The pressure for blood flow is also much reduced. Many veins have valves to prevent the backward flow of blood. The internal diameter of the veins is much more than the arteries (diagram 94); veins therefore offer less resistance to the flow of blood.

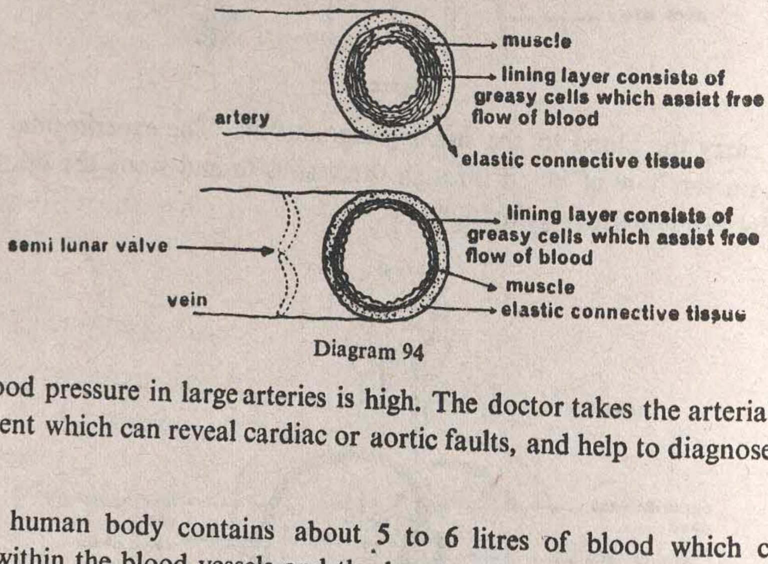

muscle
lining layer consists of greasy cells which assist free flow of blood
artery
elastic connective tissue
lining layer consists of greasy cells which assist free flow of blood
semi lunar valve
muscle
vein
elastic connective tissue

Diagram 94

The blood pressure in large arteries is high. The doctor takes the arterial pressure of his patient which can reveal cardiac or aortic faults, and help to diagnose diseases.

BLOOD

A normal human body contains about 5 to 6 litres of blood which constantly circulates within the blood vessels and the heart. Blood is a thick, red and viscous liquid which sticks to the finger. It has a faint odour and a salty taste.

Activity 3. Examine a drop of your blood under the microscope. Rub the end of a clean finger with some cotton wool soaked in alcohol. Prick the inside of a finger behind the nail with a quick jab of a sterilized needle. Press lightly to get a drop on a microscope slide at one end. Put a wide cover glass on it at an angle so as to touch the blood with the edge and slide it forward to obtain a thin smear (diagram 95). Wave the slide in air to dry it and examine under a high power microscope.

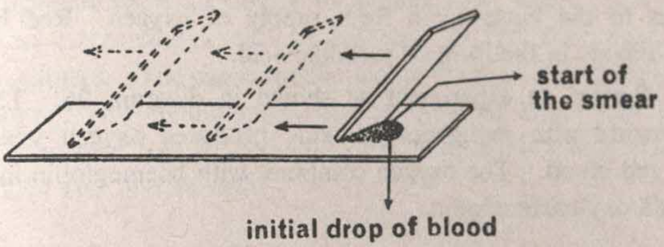


Diagram 95

It is observed that blood consists of a clear yellowish liquid called ***plasma*** in which float a large number of very minute bodies called the ***corpuscles.***

RED CORPUSCLES

These cells are formed in the red marrow of bones. At first they have nuclei like other ordinary cells but lose them as they grow older and become hollowed discs of about 0.007 mm in diameter. They live for about 120 days and are then destroyed by the ***spleen.*** There are about 5 million red corpuscles in every mm^3 of blood so that a man's body contains over 30 billion corpuscles.

The function of the red blood corpuscles is to carry oxygen from the lungs to all other parts of the body. Each corpuscle carries a little of the red substance called ***haemoglobin*** which is a compound containing a little iron. When in contact with plenty of oxygen, as in the lungs, the haemoglobin combines with oxygen to form bright red ***oxyhaemoglobin.*** The blood travels round through the arteries and capillaries to the tissue cells where oxygen is required by the cells. The oxyhaemoglobin gives up its oxygen and turns into purplish haemoglobin.

$$\text{oxygen} + \text{haemoglobin} \underset{\text{in tissues where oxygen is scarce}}{\overset{\text{in lungs where oxygen is plenty}}{\rightleftarrows}} \text{oxy-haemoglobin}$$

This blood containing haemoglobin now returns to the heart through the veins

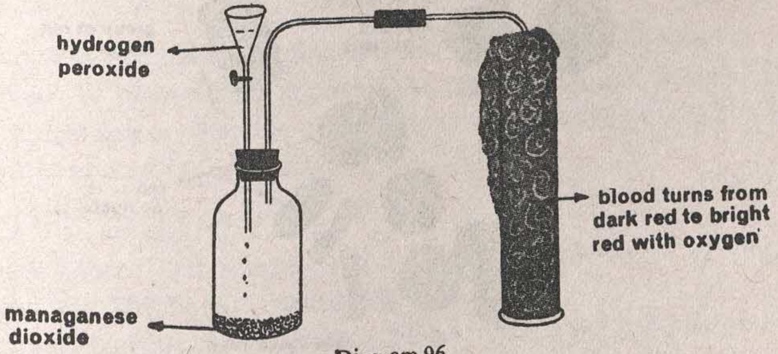


Diagram 96

and then goes to the lungs for a fresh supply of oxygen. Red blood cells also carry carbon dioxide in the form of carbonic acid.

Activity 4. Set up an experiment as shown in diagram 96. The reaction of hydrogen peroxide with manganese dioxide produces oxygen which is bubbled through dark red blood. The oxygen combines with haemoglobin in the blood to form bright red oxy-haemoglobin.

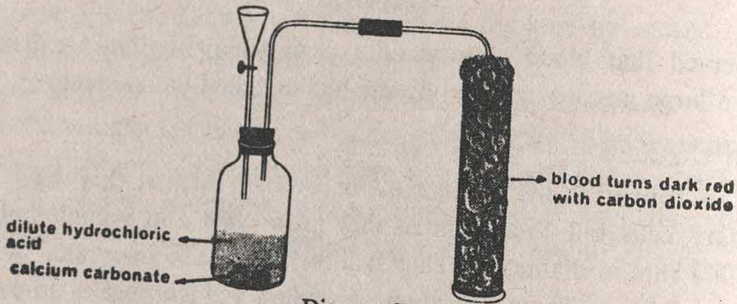


Diagram 97

Now set up another experiment to produce carbon dioxide by the reaction of dilute hydrochloric acid on calcium carbonate. When the gas is allowed to mix with blood rich in oxy-haemoglobin, the blood turns purple red in colour (diagram 97).

WHITE CORPUSCLES

The white corpuscles are colourless cells of various shapes which have rounded or bead-like nucleus. They are much smaller in number, from about 5 to 7,000 per mm^3 of blood.

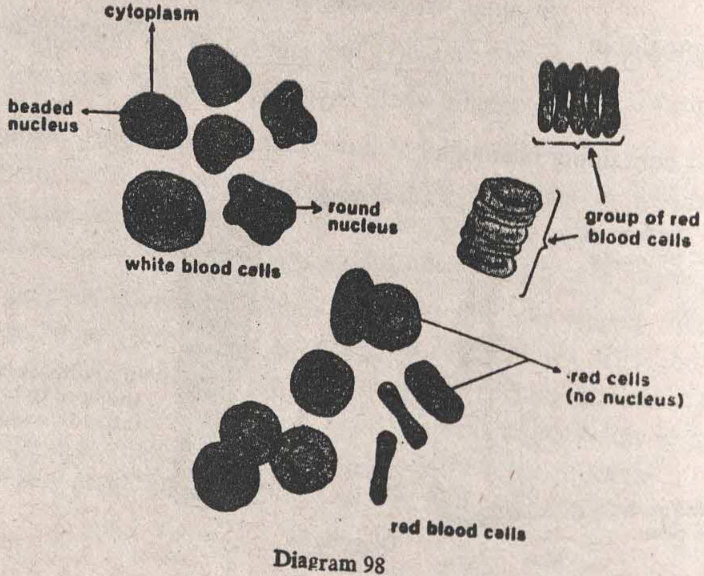


Diagram 98

The white corpuscles have the ability to change their shape somewhat like the amoeba, and form outgrowths called pseudopodia. In fact they behave like independent living creatures. The pseudopodia enable them to escape through capillary walls. They capture and engulf solid particles such as dead cells and bacteria. They play an important role in defending the body against infection by bacteria, and removing dead and injured cells.

THE PLASMA

The light straw-coloured liquid in which the blood corpuscles float is called the plasma. It has a water content of about 90 per cent. The 10 per cent of solid content in the solution is mostly proteins (7 to 8 per cent), glucose (0.1 per cent) and salts (0.9 per cent). The dissolved gases are nitrogen, oxygen and carbon dioxide. Chief among the mineral salts is sodium chloride (0.6 per cent).

By quantity, the plasma constitutes about 55 per cent of blood; the rest of the material consists of mainly the red corpuscles (diagram 99).

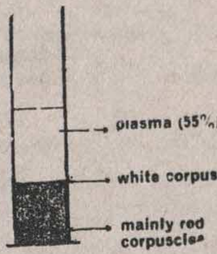


Diagram 99

PLATELETS AND THE CLOTTING OF BLOOD

Blood collected in an open vessel soon clots or coagulates aided by minute structures, called the ***platelets***, in the blood (diagram 100). The clot is a semi-solid, viscous, jelly-like mass. It gives a liquid called ***serum***. The clot is made by tangled threads of ***fibrin*** which imprison the corpuscles. The fibrin is formed in the body from ***fibrinogen*** when the platelets or cells are destroyed. Fibrinogen is a type of protein present in the plasma.

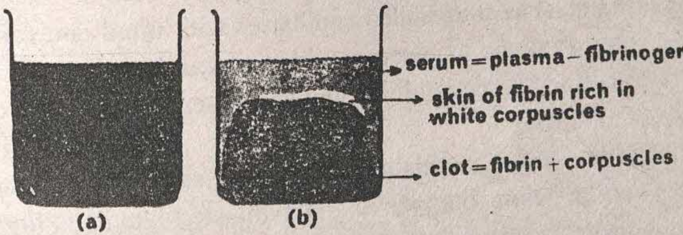

serum = plasma − fibrinogen
skin of fibrin rich in white corpuscles
clot = fibrin + corpuscles
(a)
(b)

Diagram 100

TISSUE FLUID OR LYMPH

You will have noticed that sometimes a colourless liquid instead of blood comes out of a scratch. This liquid is called tissue fluid.

We have seen that the capillaries carry blood to reach the cells and thus provide them with oxygen and food material. However, the blood itself does not enter the cells. Some of the plasma escapes through the thin wall of the capillaries and spreads among the cells of the tissues. This fluid contains most of the blood content except the red corpuscles and some proteins. It is a colourless fluid called the ***tissue fluid.***

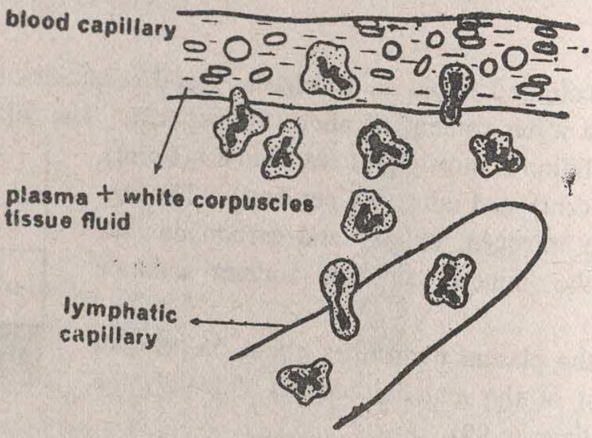


Diagram 101

After passing among the cells, the greater part of this fluid returns to the capillaries carrying waste products away from the cells. Some of it enters another independent system of vessels called the ***lymphatics***; the fluid is then called the lymph. The lymphatics start as thin-walled capillaries with blind end (diagram 101). The lymph flows through them to bigger vessels assisted by valves in them. The fluid ultimately returns into the general circulatory system when it is drained into a vein at the base of the neck.

Along their course the lymph vessels have nodes or swellings which act as filters. They also produce certain white corpuscles. An infected lymph is filtered so that the blood stream is protected from infective matter such as from diseased tissues.

BLOOD GROUPS

Blood transfusion becomes necessary when a person loses a great deal of blood in accidents, operations, etc. However, in such transfusion, the blood of the donor should mix into that of the recipient without any harmful effects. There are four types of blood groups known. If the blood is not compatible, the red blood cells clump together and form clots. When the clots are excessive, sickness and even death may result. Bloods are grouped according to the presence or absence of certain substances in the serum and the red corpuscles. The following table shows whether the groups are compatible or not :

		Donor's group			
		O	A	B	AB
Recipient's group	O	Yes	No	No	No
	A	Yes	Yes	No	No
	B	Yes	No	Yes	No
	AB	Yes	Yes	Yes	Yes

A person with blood of O group is called a ***universal donor*** because the blood can be given to any person. A person with blood group AB is called a ***universal recipient*** because he can accept blood from any donor.

Another important blood factor is the ***Rhesus*** or ***Rh factor*** present in blood cells. It is capable of causing clumping, when the red cells stick together, under certain situations. Most people are Rh positive, i.e. their blood contains this chemical. The introduction of the Rh positive factor into the blood of another person with Rh negative factor can produce a certain substance which, if in large quantity, may become fatal. This may take place due to blood transfusion.

It is important to note that the blood of an expectant mother can be Rh negative, and that of the embryo Rh positive; in such a case there is the danger that an anti-Rh substance produced by the mother may diffuse into the foetus and cause its death.

PROBLEMS

1. What are the important functions of the circulatory system ? Which are the organs responsible for the circulation of blood ?
2. Describe the function and differences between the three types of blood vessels which form part of the transport system in our body.
3. With the help of a simple and clear diagram, explain the working of the heart in mammals.
4. Trace the likely path of a red blood cell from a narrow vein in a finger till it comes out of the heart in the aorta. What change is likely to take place in its chemical composition ?
5. Describe the structure and functions of the red and white corpuscles in our blood, Where are the red blood cells produced ? Why are they red ?

6. What causes the sound of a heartbeat ? How many beats normally take place in one minute ? Why is the heartbeat rate increased after exercise ?
7. What causes a pulse ? Why is it felt in the arteries but not in the veins ?
8. What is tissue fluid ? What are the lymphatic vessels ? What role do the lymphatic glands play in our body ?
9. What are the different blood groups ? Which group is a universal donor ? Which group is a universal recipient ?
10. What is the difference between blood and tissue fluid ? Which compounds of blood are responsible for clotting ?
11. State the path of an oxygen molecule from the lung to an actively respiring muscle cell.
12. Why is there no circulatory system in Paramoecium and Hydra ?

14

Assimilation of the Food

Every organism must eat to stay alive. Life is maintained only by a regular supply of food. Hunger and thirst are signs of bodily needs. Food is required by us for the following bodily functions:

(*a*) To obtain energy for carrying out day-to-day activity and to keep our body warm. The energy required by an individual depends upon his age, size, sex and physical activity. An average man working in the office requires about 10,000 joules (2,500 calories) of energy in one day. A person engaged in physical labour may need about double this quantity of energy.

(*b*) For the supply of materials for growth. Not only children grow up in size and weight, but also such parts as hair and nails which continue to grow always.

(*c*) For the repairs and replacement of injured and worn out tissues. A wound gets healed, and new tissues replace worn out tissues in our body by obtaining material from the food that we eat.

(*d*) To maintain our body in good health. Some chemicals we obtain from food are in very small quantity but a regular supply of these is very essential to regulate biological functions within the body.

In the course of a day we eat and drink all types of food., From a chemical point of view the nutrients in the food fall into the following three categories: (*i*) carbohydrates, (*ii*) fats, and (*iii*) proteins. Other kinds of food needed by our body are: (*a*) water, (*b*) minerals, and (*c*) vitamins.

CARBOHYDRATES

Carbohydrates are fuel nutrients which are present in starch and sugar. Rice, wheat, potatoes and some vegetables are rich in starch. Sugar in the form of glucose and fructose is present in many fruits, honey and sweets. Each gram of carbohydrate provides about 17 joules of energy when assimilated in our body.

Carbohydrates are compounds containing carbon, hydrogen and oxygen atoms; the hydrogen and oxygen atoms are in the ratio of 2:1. During digestion all carbohydrates turn into glucose, $C_6H_{12}O_6$, or fructose. These burn in the body to give energy, carbon dioxide and water.

Activity 1. The presence of starch in a food material can be tested as follows.

Place a drop of iodine on a potato slice. It changes into a blue-black colouration showing the presence of starch. This is called the ***Iodine test***.

Activity 2. Prepare ***Fehling's solution*** which is deep blue in colour. Add a small quantity of glucose solution to it and boil. The colour gradually changes to brick-red due to the formation of copper (I) oxide precipitate. The copper sulphate present in Fehling's solution reacts with glucose to form the precipitate. Test juices of orange, grape, etc. to find the presence of glucose or other reducing sugars in them.

FATS

Fats are fuel nutrients also used for storage of energy. Almost every cooked food contains fat in some form. Vegetable oils, butter and mutton fat are the main sources of fats. When cells in our body oxidize fats, each gram of fat releases 35 joules or more of energy. Thus fats are energy packets in a concentrated form. When our body does not need energy which is available in them, it is stored in the body as fat. Our body converts even excess of carbohydrates into fats for storing.

Fats also contain the same three elements—carbon, hydrogen and oxygen, but unlike the carbohydrates, the proportion of hydrogen to oxygen atoms is not 2:1.

Activity 3. A simple ***test for fat*** is to put a drop of it on a paper. It leaves a greasy mark and turns the paper translucent. Another sensitive test is as follows. Dissolve it in a small quantity of ethanol (methylated spirit free from water). When this solution is poured into a small quantity of cold water, the fat forms a suspension which looks cloudy or milky.

PROTEINS

Proteins are repairers and builders of tissue. The important sources of protein are white of egg, meat, lentils, pulses such as beans and peas, and milk.

All proteins contain carbon, hydrogen, oxygen and nitrogen; some also contain the elements phosphorous and sulphur. These compounds are very complex but are now known to be built up of simpler molecules called ***amino acids***. When any proteins are made to combine with water, they break down into the simpler units, amino acids, which are able to change into other proteins in the body.

All animal tissues are formed out of proteins which contain nitrogen. Fats and carbohydrates do not contain nitrogen and have no power to build up protoplasm in cells. On the other hand, proteins yield the same amount of energy as carbohydrates and can provide energy to the body in the absence of fats and carbohydrates in our food. However, the main function of proteins is to build materials for the formation of protoplasm in cells needed for growth and repair.

Activity 4. Place a drop of concentrated nitric acid on cooked egg white. A yellow colouration will be produced. Add ammonium hydroxide and it turns to orange. This is the ***Nitric acid test*** for protein.

Activity 5. Add a protein food material such as diluted egg white to Millon's reagent and boil. The solution develops a pinkish brown colouration. This is called the ***Millon's test.***

Activity 6. Add caustic soda solution to a protein and to this mixture add a drop or two of copper sulphate solution. A mauve colouration indicates the presence of protein. This is called the ***Biuret test.***

Activity 7. Heat some hair or nails of animals in a test tube. Test the gas given off with damp red litmus. The litmus turns blue. This shows the presence of ammonia (NH_3), showing that a protein material is a compound of nitrogen.

WATER

Two-thirds of our body is water. It is the main constituent of cell protoplasm, digestive juices, urine and sweat. It is mainly needed for the transport of materials within the body; water is the medium through which chemicals enter and leave the cells. Water is also required to regulate our body temperature. The daily consumption of water depends upon climate and activities of the individual but most of our food items contain a lot of water.

MINERAL SALTS

Mineral salts are needed by us in very small quantities but they are essential for a healthy functioning of our organs. There are at least 20 elements absorbed by our body in various quantities, and their percentage by weight is given in the table below. This percentage remains constant in the normal human body.

Element	*% weight*	*Element*	*% weight*
Oxygen	65.00	Sulphur	0.25
Carbon	18.00	Chloride	0.15
Hydrogen	10.00	Sodium	0.15
Nitrogen	3.00	Magnesium	0.05
Calcium	1.50	Iron	0.004
Phosphorous	1.00	Iodine	traces
Potassium	0.35	Others	traces

The largest supply of elements, almost 96 per cent, is from carbohydrates, fats and proteins we eat. Calcium and phosphorous are required for the formation of bones and teeth. Potassium and magnesium are useful for muscular contraction. About 0.9 per cent of blood contains salts, mostly sodium chloride. Iron is an essential element for the manufacture of haemoglobin in blood. Iodine is present only in small traces but in its absence the ***thyroid gland*** in our neck will not function well; this adversely affects the rate of cell oxidation.

VITAMINS

Vitamins are essential regulators of tissue activity. They are required in only very small quantity but are very essential for a regular function of various organs. These vitamins are not normally produced in our body; they have, therefore, to be present in our food. A number of vitamins have been discovered so far. Lack of any one of them causes a ***deficiency disease.***

(*a*) *Vitamin A* is present in cod-liver oil, milk, carrots, tomatoes, butter and cheese. It is important for the protection of eyes, lungs, etc. Deficiency of this vitamin results in dry skin, dry-eye (which may result in night blindness) and stunted growth.

(*b*) *Vitamin B complex* is a mixture of several vitamins such as ***thiamin, riboflavin*** and ***nicotinic acid.*** It is present particularly in yeast extract, husk of cereals and pulses, milk, liver and eggs. Deficiency of thiamine results in a deficiency disease called ***beriberi*** which causes nervousness, loss of appetite and paralysis. Absence of riboflavin causes sores at the corners of mouth and eye diseases. Lack of nicotinic acid leads to skin diseases.

(*c*) *Vitamin C* or ascorbic acid is present in citrous fruits such as oranges, lemons and limes, fresh vegetables such as tomatoes, cabbages and green vegetables. Lack of this vitamin results in a disease called ***scurvy*** which causes bleeding of gums and swelling of joints. It is worth noting that high temperature destroys vitamin C; these fruits and vegetables must therefore be taken fresh and not cooked.

(*d*) *Vitamin D* or calciferol is found in liver oils, yellow of eggs and butter. Our skin also produces this chemical when exposed to sunlight. Deficiency of this vitamin leads to ***rickets*** which causes decaying teeth and weak, distorted bones. Vitamin D controls the rate of absorption of phosphorous and calcium by the body.

(*e*) *Vitamin E* is present in green vegetables and animal oils. Lack of this vitamin is a cause of sterility.

(*k*) *Vitamin K* is present in green vegetables and is responsible forblood clotting.

BALANCED DIET

It is obvious that our diet must contain the right amounts of various chemicals in order to lead a healthy and active life; such a food is called a balanced diet. A variety of food generally caters to our bodily needs; a particular dish alone will never contain all nutrients required by our body. This leads to malnutrition.

Hunger is an indication of the necessity of food; plenty of food may satisfy our hunger but it may not satisfy our bodily needs. A tasty food is not necessarily the best diet. A balanced diet is essential for a healthy working body.

DIGESTION

The food that we eat has to reach the individual cells before it can be utilised in any way. It is, however, not in a suitable form and has to be changed physically and chemically. For example, the crumbs of bread or grains of rice we eat cannot reach cells nor can they be used in their present form. They are processed in two ways. Firstly, they have to be broken down in size and made into a soluble form so that the blood can transport them to the cells. Secondly, they have to be chemically changed into simpler soluble forms which the blood and bodily cells can absorb. The breaking down of complex molecules of food into simpler and soluble molecules, which can be absorbed by the blood and later utilised by the cells, is called digestion.

Digestion involves the following chemical changes in the complex, insoluble molecules of carbohydrates, fats and proteins:

(*a*) Carbohydrates combining with water to form glucose and fructose.

(*b*) Fats combining with water to form fatty acids and glycerol.

(*c*) Proteins combining with water to form amino-acids.

These end products are absorbed by the blood. It is however important to note that the combination of food and water to form the soluble, simpler molecules cannot take place unaided. The body manufactures certain organic catalysts called the ***enzymes*** which at various stages of digestion activate the process. At least nine different enzymes are produced by the food canal and its associated glands.

THE DIGESTIVE SYSTEM

Besides producing the enzymes, the digestive system provides the right conditions of temperature, time, movement (stirring), pH, etc. for the enzymes to work best. The system also provides for absorption of the useful food and removal of the food which is not digested.

The digestive system of man is made up of a digestive tract called the ***alimentary canal*** through which the food passes, and the ***digestive glands***, which transform the foodstuffs by the secretion of digestive juices. The alimentary tract comprises the mouth, the pharynx, oesophagus, the stomach, the small intestine, the large intestine, the rectum

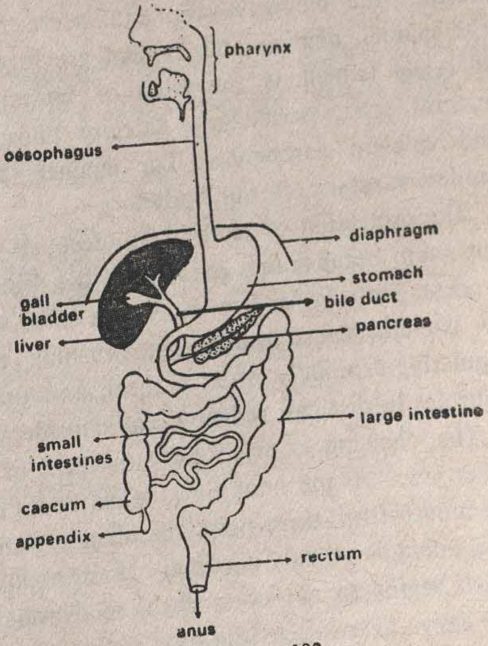


Diagram 102

and the anus (diagram 102). This has two openings, one in the beginning, the mouth, and the other at the end, the anus. It is over 8 metres long, of which the small intestine alone is about 5½ m long. The digestive glands open into the alimentarv canal at various points. These are the ***salivary glands***, the ***liver*** and the ***pancreas***. There are two more sets of glands which are embedded into the walls of the stomach and the small intestine.

THE MOUTH

Food is taken into the mouth, chewed and broken into little fragments, mixed with saliva and then swallowed. The chewing is aided by the teeth which in adults are of four types: on each side of each jaw (*i*) 2 incisors which have a sharp-edged ***crown***, (*ii*) 1 canine with a pointed crown, (*iii*) 2 premolars provided with two round elevations, and (*iv*) 3 molars with wide crowns and four elevations (diagram 103). The incisors cut the food, the canines tear it, premolars crush it and the molars grind it.

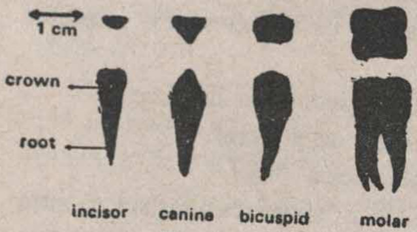


Diagram 103

The teeth appear to be insensitive but are living structures which fit into sockets in the jaws. Enamel covers the crown and cement covers the root (diagram 104). In the centre is the pulp which is soft and contains the blood vessels and nerve fibres. The enamel, dentine and cement are made up of ***ossein*** (which is the basis of bones) and mineral salts, particularly calcium phosphate and calcium carbonate. The enamel is the hardest substance in our body.

The protection of teeth from decay is very important because they greatly aid the digestive process. Rotting food in the mouth acted upon by bacteria cause the decay; brushing teeth regularly, especially after a meal, and use of flourides in diet can reduce decay considerably.

The chewing is aided by movement of the lower jaw. At the same time, saliva pours into the mouth from three pairs of salivary glands.

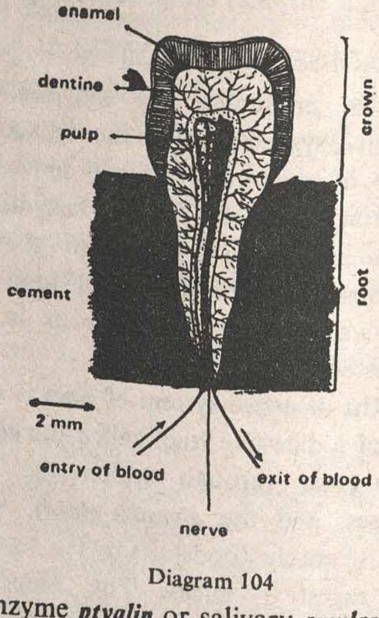
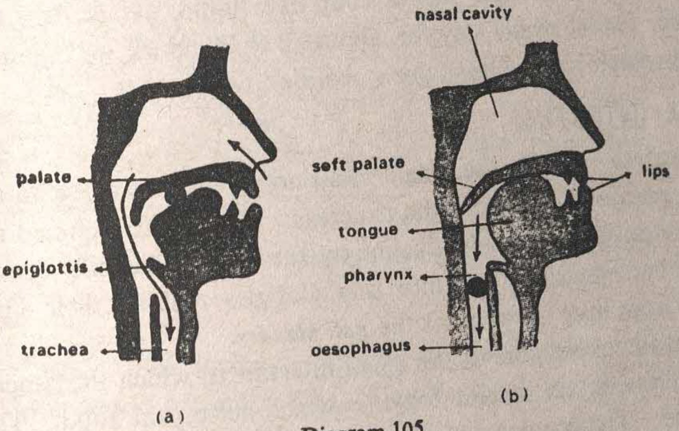


Diagram 104

The saliva is slightly alkaline. It contains the enzyme ***ptyalin*** or salivary ***amylase*** which begins to act upon starch to convert it into a simpler form called ***maltose***. The saliva also softens the food making it easy to swallow.

The tongue rolls food particles to the back of the mouth into the ***pharynx.*** It is important to note that during swallowing the lips are closed, the soft palate closes the nasal passage, and the ***epiglottis*** closes the entrance to the respiratory tube (diagrams 105 *a* and *b*).



(a)

(b)

Diagram 105

From the pharynx the food enters the oesophagus leading to the stomach. In the oesophagus food moves slowly by the periodic relaxation and contraction of of inner wall muscles. This rhythmic squeezing of food is an involuntary process called ***peristalsis.***

THE STOMACH

The stomach stores, further digests and mixes the food. Gastric glands which line the inside of the stomach secrete a digestive juice called the gastric juice. It contains two enzymes, ***pepsin*** and ***renin,*** of which the latter helps clot milk and is important only for young mammals. The gastric juice also contains dilute hydrochloric acid. The acid provides suitable acidic medium for the pepsin to act on the proteins, which breakdown into simpler molecules called ***peptones.***

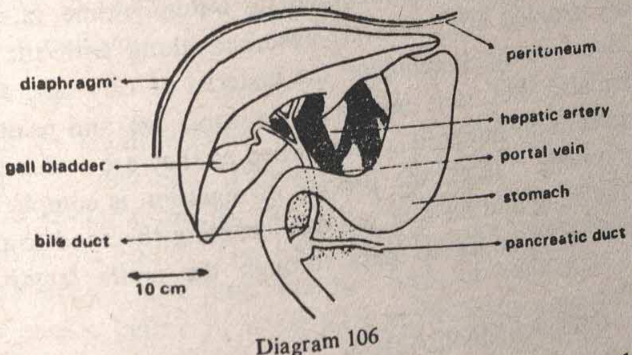


Diagram 106

The gastric juice also contains ***mucus*** which protects the stomach wall from action of the acid and pepsin; lack of mucus may cause damage of cells lining the stomach wall and result in an ***ulcer.***

The food in the stomach gets thoroughly mixed by contraction and expansion of muscular tissues and changes into a soup-like liquid. It is then forced into the small intestine. Most meals stay for about 3 to 4 hours in the stomach. Both ends of the stomach have valves which operate involuntarily.

THE SMALL INTESTINE

As the food moves towards the small intestine, it gets mixed with ***bile*** from the liver and the ***pancreatic juice*** from the pancreas. The acidic liquified food from the stomach is neutralised and made alkaline by the bile. The bile does not contain any enzymes but emulsifies fats into tiny globules making their digestion easier. Excess of bile from liver is stored in the ***gall bladder.***

Duodenum is the upper part of the small intestine in which the pancreatic juice is brought in. This contain several enzymes which act on the food. The pancreatic juice is alkaline. The enzyme ***trypsin*** acts on proteins producing more peptones. ***Amylase*** acts on starch producing more maltose. ***Lipase*** acts on fats producing glycerol and fatty acids.

The small intestine also has glands which produce more enzymes present in the intestinal juice. This is also alkaline in nature. The enzyme ***erepsin*** acts on peptones to produce amino acids. ***Invertase*** acts on cane sugar producing glucose and fructose. ***Maltase*** acts on maltose to convert it into glucose. ***Lactase*** acts on milk sugar and converts it also into glucose and galactose.

The final products of digestion are glucose and fructose, amino acids, fatty acids and glycerol. All of these dissolve in water. Some fats which remain undigested as tiny droplets are, however, absorbed along with the final products. Our food canal does not digest cellulose, the material of cell-walls of plants, unlike some other mammals. But it is important as roughage and passes through with the faeces. Vitamins and minerals are absorbed as they are without any treatment in the digestive system. Thus, the process of digestion is completed in the small intestine. This is a long and narrow passage enabling the food to proceed slowly. The food takes over 3 hours to pass through the entire length of the small intestine.

ABSORPTION AND ASSIMILATION

The nutrients are now ready for absorption which is a process of their removal from the digestive system into the blood stream. The surface of the small intestine is lined with millions of tiny projections called the ***villi.*** They enable the surface to be increased enormously (diagram 107).

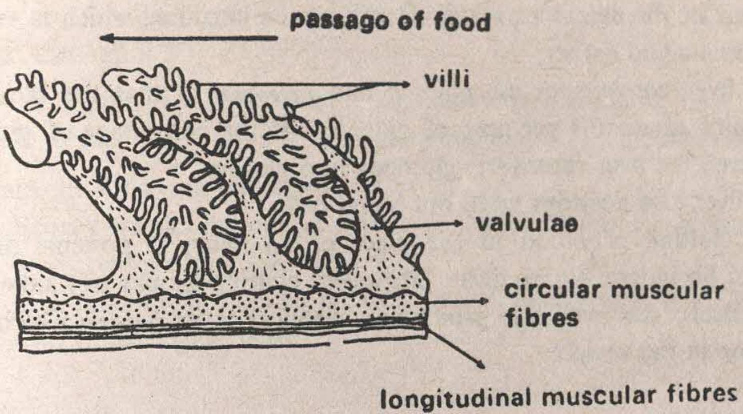


Diagram 107

The structure of each villus shows a network of blood capillaries surrounding lymph vessel called the ***lacteal*** (diagram 108). Simple sugars, amino acids, minerals and vitamins pass from the small intestine directly into the blood capillaries which carry them towards the heart. Glycerol and fatty acids diffuse into the lymphatic vessels; they join the blood vessels near the left shoulder. Thus all nutrients enter the blood stream by which they are transported to cells in the body.

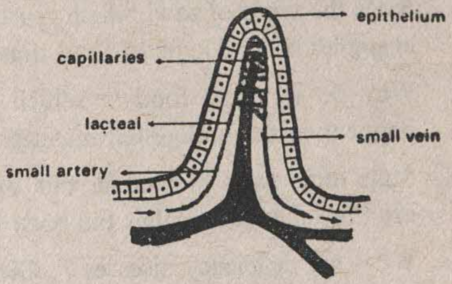


Diagram 108

Cells utilize the nutrients and oxygen obtained from the blood to release energy and to build more protoplasm material. This process is called ***assimilation.***

THE LARGE INTESTINE

Undigested food from the small intestine now enters the large intestine through a valve which opens at short intervals. This rejected material consists of cellulose, seeds, living and dead bacteria, mucus, etc. As it moves along, water from the material is reabsorbed in the body. The solid or semi-solid remains then passes through the rectum as faeces. The large intestine and the rectum both serve to temporarily store the faeces before it is expelled through the anus by voluntary muscular action.

THE LIVER

The production of bile is one of the many functions of the liver. In the human body, liver is the largest gland. The blood from the intestine passes to the liver and contains the amino acids, glucose and other simple sugars absorbed in the blood.

(*a*) A part of the excess amino acids are turned into urea which is excreted by the kidneys as studied earlier.

(*b*) The liver converts excess glucose into ***glycogen*** so that the blood stream always contains about 0.1 per cent of glucose. If the percentage of glucose falls below this level, the liver reconverts glycogen into glucose.

(*c*) The liver also destroys worn out blood cells.

(*d*) The clotting of blood at the place of an injury is possible due to the production of fibrinogen by the liver. However, clotting should not take place in the blood vessels; the liver also produces a chemical called ***heparin*** which prevents such a clotting in the vessels.

PROBLEMS

1. State the types of food which must be present in a balanced diet. Give two examples of each type of food present in our diet.
2. Why do we need food ? Which types of food serve as nutrients ? What happens to the undigested material in our diet ?
3. State three types of food in our diet which are not soluble in water. How are they changed so that the body can absorb them ?
4. What are deficiency diseases ? Give three examples of deficiency diseases and state the type of food essential to avoid them. In which natural sources are these food items present ?
5. Which minerals are present in our body ? Give some examples to bring out the importance of some of these minerals for a healthy living.
6. Draw a simple and clear labelled diagram of the stomach, gall bladder, duodenum and pancreas to show how they are situated in man.
7. Describe experiments to find out the presence of (*a*) starch, (*b*) fats and (*c*) proteins (*d*) glucose in a piece of meat. Which of these are present in meat ?
8. Explain the function of three types of enzymes in our body. Give one example of each state, where it is formed and what is its action.
9. How is digested food absorbed and assimilated in our body ?
10. Explain the function of mouth in the digestive process ? What part do teeth play in this process ? How are teeth protected ?

11. What are the functions of the liver ? What effect has it on the blood that passes through it ?
12. How is food propelled through the alimentary canal ? How much time does food take to be digested and absorbed in our body after it is eaten ?
13. Explain the following statements:
    - (*a*) Scurvy was a common disease in the 18th century found among people who went on long sea voyages.
    - (*b*) It is advised that boiled milk for babies should always be supplemented with fresh orange juice.

15

Respiration and Excretion

All living cells require food and oxygen to maintain their activity. These cells are capable of breaking down glucose molecules in the food by making use of oxygen and release energy into other available forms. This process is called ***respiration.***

RESPIRATION AND ENERGY

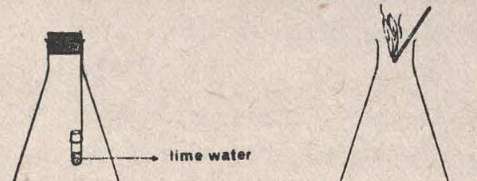
The chemical reaction involved in the process of respiration carried out by all living cells can be written as follows:

$$\textit{oxygen}+\textit{glucose}\text{ from food}\xrightarrow{\text{(respiration)}}\textit{carbon dioxide}+\textit{water}+\textit{energy}$$

Respiration is therefore a form of combustion although the process is more complex. ***Enzymes*** play a very important part in respiration.

Activity 1. Take some water in two conical flasks and drop in each of them about 15 peas or beans. Stand a small test tube containing lime water in one of the flasks and close the opening with a cork (diagram 109 *a*). Cover the top of the second flask with a glass plate smeared with vaseline to make an air-tight fit.

You will notice that after a few days the lime water turns milky showing the presence of an increased quantity of carbon dioxide. If a lighted taper is introduced into the second flask, the flame goes out (diagram 109 *b*) showing that oxygen in the flask has been consumed. The seeds must have taken the oxygen, giving out carbon dioxide.



(*a*) (*b*)

Diagram 109

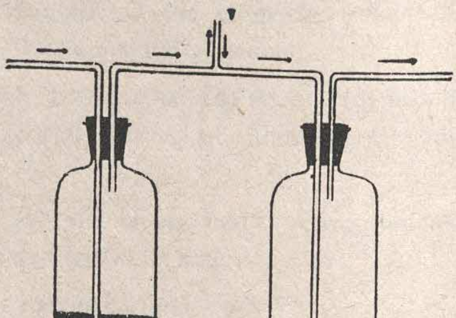
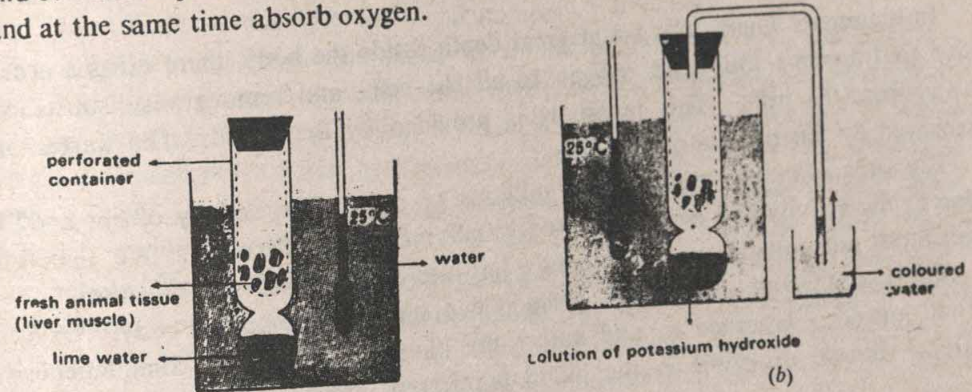


Diagram 110

Activity 2. Take some lime water in two bottles fitted with rubber stoppers. These are fitted to an apparatus shown in diagram 110, so that if you suck in through the tube *T*, the air enters through one bottle; when you breathe out, the air goes out through another bottle. Now suck in and out for a few times. Both the bottles with lime water in them are kept close to each other for comparison. Notice any difference in colour in the two samples.

You will observe that the lime water through which the exhaled air is passed forms a milky suspension. This is due to the increased proportion of carbon dioxide.

Activity 3. Set up two perforated containers as shown in the diagrams 111 *a* and *b*. The experiments demonstrate how living tissues give off carbon dioxide and at the same time absorb oxygen.


perforated container
25°C
water
fresh animal tissue (liver muscle)
lime water
25°C
coloured water
solution of potassium hydroxide

(*a*) (*b*)

Diagram 111

Activity 4. Soak some peas and beans in water and put them in a thermos flask. Insert a thermometer so that the bulb is in the middle of the seeds. Record the temperature and fix a stopper or close the mouth of the flask with cotton wool (diagram 112). Record the temperature every day for a few days. You will observe that the temperature is increased showing a release of energy.

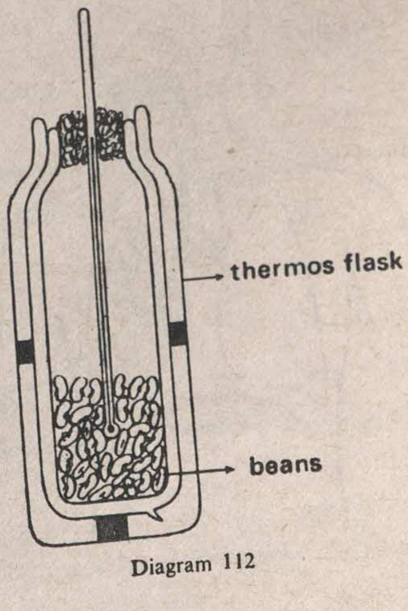


Diagram 112

In all organisms, the cells have an ***optimum*** temperature at which they work most efficiently; above this temperature the enzymes would get destroyed. The normal temperature of the human body cells is 37°C (98.4°F). The heat required for maintaining this temperature is provided by respiration.

CELL AS A UNIT OF FUNCTION

Respiration goes on day and night whether we sleep or work. If respiration ceases, the organism dies; this may happen due to lack of food or oxygen. It is possible for us to fast a long time but we cannot do without air for more than a few minutes.

In the process of respiration, cells produce carbon dioxide and water. The carbon dioxide is a waste produce, and water not required in large quantity has also got to be removed from the body. These waste materials leave a cell through the general body surface in microscopic animals, such as amoeba. In plants the carbon dioxide may escape to the outside air or get used up in the leaves during photosynthesis.

In mammals where cells are at great depth inside the body, there exists a necessity to transport food and oxygen to all the cells, and remove waste substances away from the cells. This transport is provided by the blood. The wastes are removed by the process of ***excretion.***

Big organisms are made up of millions of cells. The activity of our body is due to the activity and energy released by all the cells collectively. We therefore call a cell not only the unit of structure but also of function in an organism.

The exchange of gases takes place at two stages in the human body. Oxygen from outside is breathed in and enters the blood in the lungs. Simultaneously, carbon dioxide dissolved in the blood is released. This exchange of gases in the lungs is called ***external respiration.*** The exchange of gases through the capillaries with cells where oxidation of organic fuel takes place with the release of energy and carbon dioxide is called ***internal respiration.***

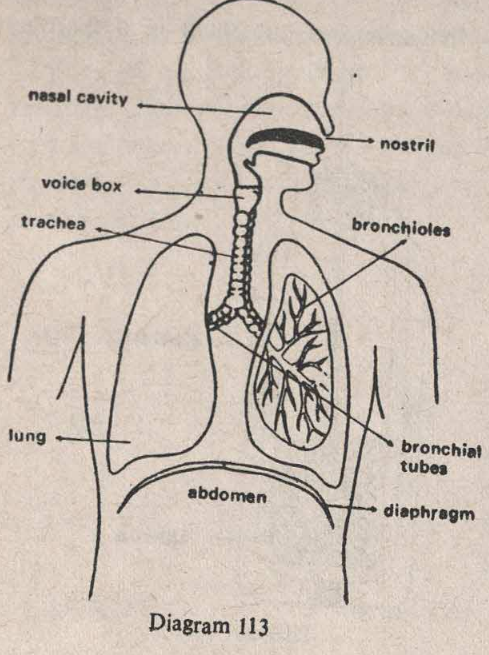


Diagram 113

THE RESPIRATORY PROCESS

The organs which take part in the external respiratory process are the lungs and the passage which carry the air to and from the lungs. The nose is the organ designed for entry of the air although the mouth also can draw in air when a large supply is needed. The hairs in the nostrils obstruct large dust particles from entering. The air is then warmed and moistened in the ***nasal cavity*** (diagram 113).

The air then passes into the wind-pipe or ***trachea*** which is a wide tube leading to two ***bronchial tubes***. Each of the tubes enters the pink mass of the lungs. The tubes then branch off into numerous smaller tubes. The smallest of these tubes, called the ***bronchioles***, are about 0.5 mm in diameter and end in small air sacs called the ***alveoli***. The air sacs have extremely thin walls giving a fine honey-comb appearance (diagram 114). There are almost 600 million air sacs in adult lungs; if spread out they will cover an area of 1000 m^2.

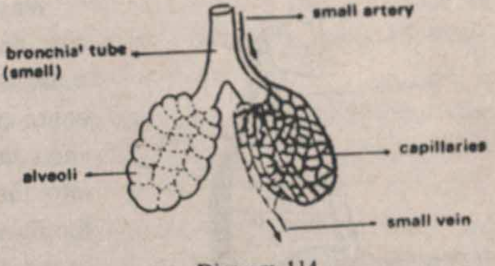


Diagram 114

The lungs are just below the collar bone and occupy a large part of the chest cavity. A diaphragm separates the chest cavity from the abdomen. Blood from the heart reaches the lungs along a branch of the pulmonary artery which divide into numerous vessels progressively decreasing in size. The capillaries form a close network round the alveoli. If arranged end to end these capillaries would extend to over 5,000 km. The exchange of gases takes place between the air sacs and the capillaries. Oxygen from the air sacs enters the capillaries when haemoglobin in the blood changes to oxy-haemoglobin. At the same time carbon dioxide and some water vapour present in the blood, which are both waste products of internal respiratory process, leave the capillaries and enter the air sacs. The oxygen rich blood is carried to the heart by veins which become progressively larger in size as the smaller ones merge together. Two veins emerge from each lung, and these four pulmonary veins enter the left auricle. The air sacs expel the air out which contains more carbon dioxide in proportion.

The following table gives the composition of inhaled and exhaled air.

	Nitrogen	Oxygen	Carbon dioxide
Inhaled air	79%	21%	0.03%
Exhaled air	79%	16%	4%

When you breathe on a clean mirror a mist forms. This shows that exhaled air contains water vapour.

BREATHING

Breathing is the mechanical process by which air gets in and out of the lungs, The expansion and relaxation of the lungs enables air to be drawn in and out of the lungs.

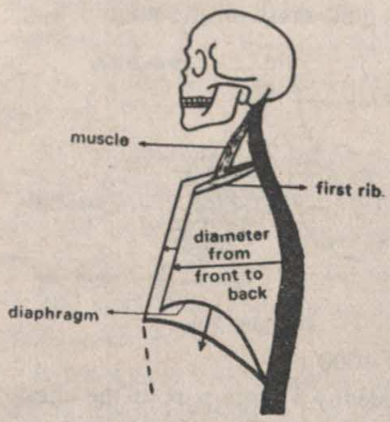


Diagram 115

When we inhale the chest expands because the ribs and sternum rise. This is because the rib muscles rise and contract. The diaphragm also contracts, flattens and drops like a piston. The chest cavity is thereby increased and air is drawn into the lungs (diagram 115). When we exhale the rib muscles relax and the diaphragm returns to the original curved position. This enables the chest cavity to contract and air is expelled out.

Activity 5. Diagram 116 shows a model which can be constructed to show the process of breathing. The sheet of rubber represents the diaphragm. By moving the sheet up and down, pressure inside the bell jar is varied. The two balloons representing the lungs inflate and deflate according to the movements of the rubber sheet.

On an average an adult breathes in and out about $\frac{1}{2}$ litre of air, and takes about 16 such ryhthmic breaths each minute. Thus the air intake is over 10,000 litres each day. This is essentially an ***involuntary*** (automatic) process controlled by nerve cells in the brain. However, when a person takes exercise, the breathing becomes faster and deeper which enables a quick removal of the larger quantity of carbon dioxide from the blood produced during internal respiration by the muscle cells.

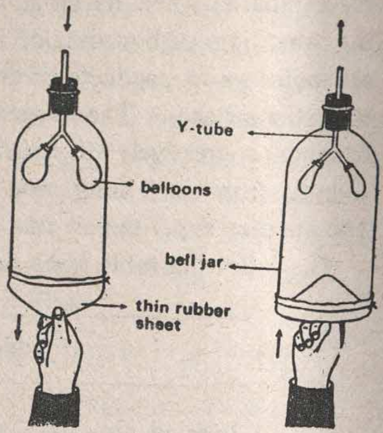


Diagram 116

RESPIRATORY DISEASES

Diseases of the lungs and throat are spread by inhaling their germs with the air we breathe in. These germs get into the air from the sputum, exhaled breath or the sneeze of infected persons. Some of these diseases are the common cold, influenza, tuberculosis, bronchitis and pneumonia.

Other more serious respiratory disorders are Hay fever, Asthma, pleurisy and lung cancer. Medical research has now established an association between smoking and lung cancer.

EXCRETION

Cell activities in a living body produce waste substances like carbon dioxide and water by respiration, and nitrogen containing compounds from the breakdown of proteins. Some of these waste products are quite poisonous to cells and must be quickly removed. This is one purpose of excretion. Excretion refers to waste products produced due to chemical reactions inside the body cells.

In the human body, carbon dioxide and some water are removed through the lungs. Lungs therefore function as excretory organs although their chief function is in the respiratory process.

The skin is also an excretory organ because some water and salts which are waste products are removed when we perspire. Perspiration is salty in taste due to the presence of the salts, largely sodium chloride. It is produced by ***sweat glands*** which open on to the skin surface. The skin has other important functions also to perform.

The food that we eat is not all assimilated by the body. Part of it is not digested. It is not involved in any chemical process within the body; this is rejected out of the body and comes out as ***faeces***. The unutilised food which comes out as faeces is therefore not called an excretory product.

Most of the nitrogenous wastes produced in our body are, however, removed by ***kidneys.*** Kidneys are the chief excretory organs in the human body. They also remove substances from blood so that the proportion of water and salts in blood is always maintained constant, this is their second important function. Life cannot continue for more than a few hours if both the kidneys are completely out of action.

THE KIDNEYS AND URINARY SYSTEM

The urinary system comprises of (*a*) two kidneys; (*b*) two ***ureters*** which are tubes leading to the bladder and carry the liquid waste in the form of urine; (*c*) the ***bladder*** which is a urinary reservoir; and (*d*) the ***urethra*** which forms a channel from the bladder to the exterior for removal of urine (diagram 117).

Kidneys are located at the back of the abdominal cavity one on each side of the vertebral column. They are shaped like beans and are reddish brown in colour. Each kidney is about 11 cm in length and has an open cavity called the ***pelvis*** which gives access to the ureter. A section of kidney shows a smooth fibrous envelope called the ***capsule***, a dark-coloured ***cortex*** which is granular in appearance, and a pale ***medulla*** with a series of 10 to 12 inward projections.

Each kidney receives blood from a ***renal artery*** which is branched off from the main artery aorta. Inside the kidneys the blood vessels branch into a large number of capillaries. Close to these capillaries are over 2 million coiled tubes called ***nephrons*** or ***renal tubules*** which form a criss-cross pattern in the kidneys. They act

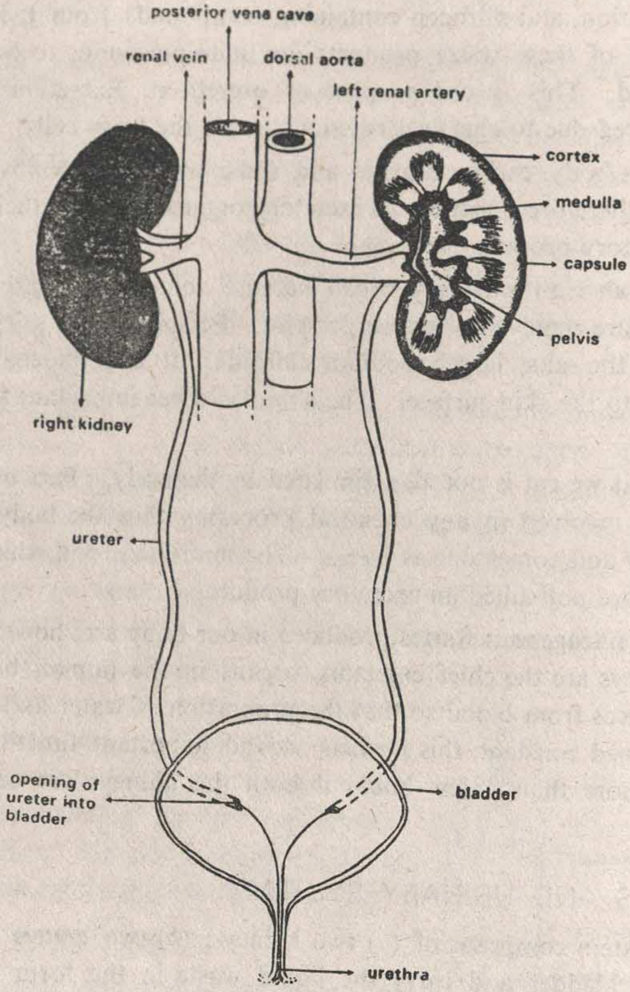


Diagram 117

as "filters" and operate in two stages as shown in diagram 118. The tubules carry excess water, urea, uric acid and other waste substances away from the blood and empty into the pelvis; this liquid called urine is about 95 per cent water. Some of the substances filtered into the renal tubules are reabsorbed by capillaries which gradually finds its way into a ***renal vein*** from where it joins the ***vena cava*** leading to the heart.

The tubes also gather some sugar which is reabsorbed but, if the blood contains a lot of sugar, some will go through with the urine. This is the symptom of ***diabetes***, a disease in which the liver cannot store sugar because of lack of ***insulin*** and hence the sugar content in blood is high. Carbohydrates are avoided in the food by diabetes patients.

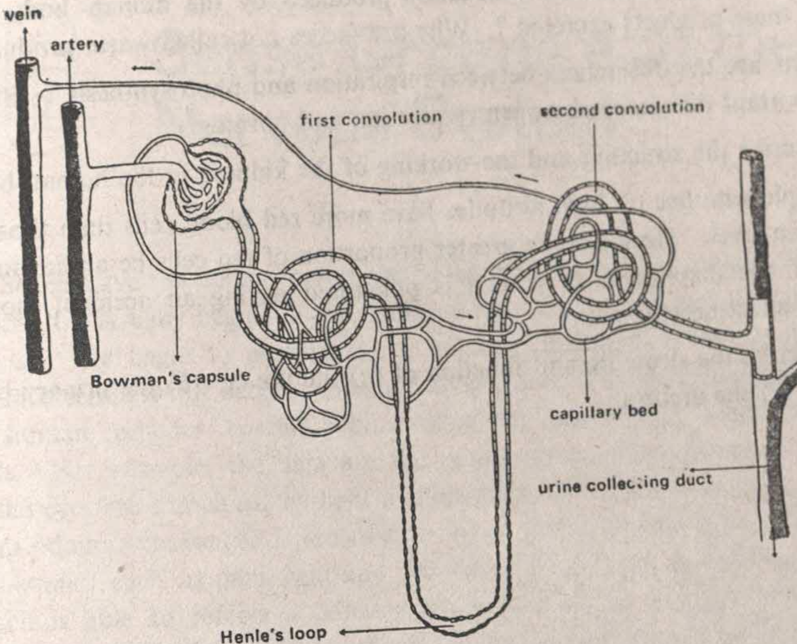


Diagram 118

The kidneys also regulate internal environment in the exchange of fluids. If you drink 4 litres of fresh water, it will all pass through urine in 2 or 3 hours. If you drink an equal amount of water with adequate salt in it, the body retains most of it; thus, the proportion of water to solid ions remains unchanged.

The kidneys also secrete certain acidic or basic substances to regulate the pH of the blood. These regulations are essential for the healthy functioning of body cells.

PROBLEMS

1. What is respiration ? Where does it take place ?
2. How are lungs caused to expand and contract ? What is the function of human lungs ?
3. Describe experiments to show that during respiration oxygen is used up and carbon dioxide is released.
4. What is the difference between breathing and respiration ? How does the oxygen inhaled during respiration reach individual cells in the body ?

5. What are the main waste substances produced by the human body? How are these products excreted? Why are faeces not called waste products?
6. What are the differences between respiration and photosynthesis? State two important differences between respiration and burning.
7. Describe the structure and the working of the kidneys in the human body.
8. People who live on high altitudes have more red blood cells than those living at sea level. How can the greater proportion of red cells be an advantage?

   If the diaphragm of a man is punctured during an accident, how may this affect breathing?
9. Describe the structure and function of (*a*) the ureter; (*b*) the urinary bladder; and (*c*) the urethra.

16

Sense Organs and the Nervous System

Living beings have the ability to respond to an external stimulus arising from their environment. A baby begins to cry, and you may even jump, at the sound of a loud noise. We begin to perspire on a hot day, especially when standing in the sun. An external factor such as noise or temperature is called a ***stimulus***.

The human body has special organs called the ***sense organs***, which receive the stimulus. For example, the ears are the sense organs which detect sound vibrations; the eyes are stimulated by light and produce the sensation of sight; the nose picks up odours; the tongue is sensitive to taste; the skin responds to touch and similar stimuli such as pain, heat and pressure. Thus there are five sense organs and each is able to receive a different kind of stimulus. All our activities are largely governed by the condition of our sense organs; deaf people (who cannot hear) or blind persons (who cannot see) have a great disadvantage in life.

It is interesting to remember that there are a number of external factors such as radio signals to which none of our sense organs are sensitive. Also, we respond to stimuli such as hunger and thirst although none of the five sense organs is involved in this.

SIGHT

The eyes are remarkable sense organs of the human body. Over 80 per cent of the information we possess is obtained through them. Not only do they detect colours and the intensity of light, but they also enable us to estimate the distance of an object from us. Our eyes produce for us a real image of an object on the retina, which is then interpreted by the brain.

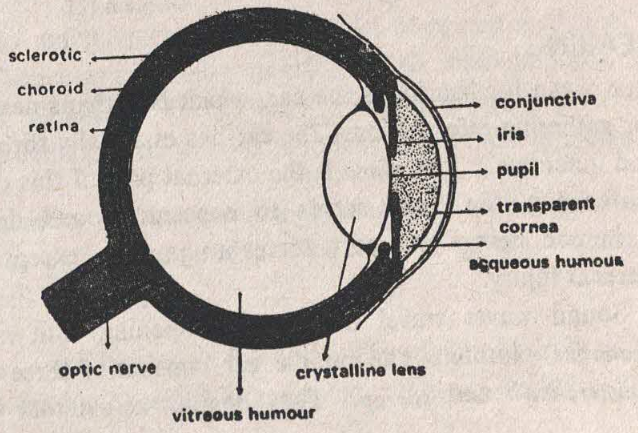


Diagram 119

The eyeball lies in a bony hollow in the skull so that it is well protected from injury. To the outer surface of the eyeball are attached bands of muscles which, by their contraction, enable the eyeball to turn over a wide angle. The eyelashes, eyelids, and the eyebrows also protect the eyeball from dust, insects, sweat, etc.

Diagram 119 gives a cross-sectional view of the eye. The converging crystalline lens enables a real, inverted and small image to be formed on the retina. Diagram 120 shows how the power of the lens is altered in order to obtain the image on the retina; this process is called ***accommodation.*** It is achieved by contraction of the ciliary muscles to which the lens is joined through connective ligaments.

The two common defects of the eye are ***short sightedness***, or ***myopia***, and ***long sightedness*** or ***hypermetropia.*** These defects can be corrected by the use of suitable lenses.

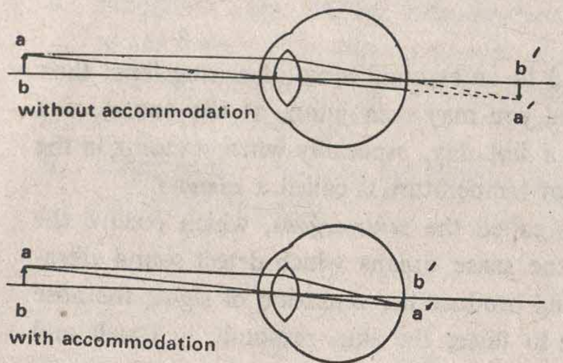
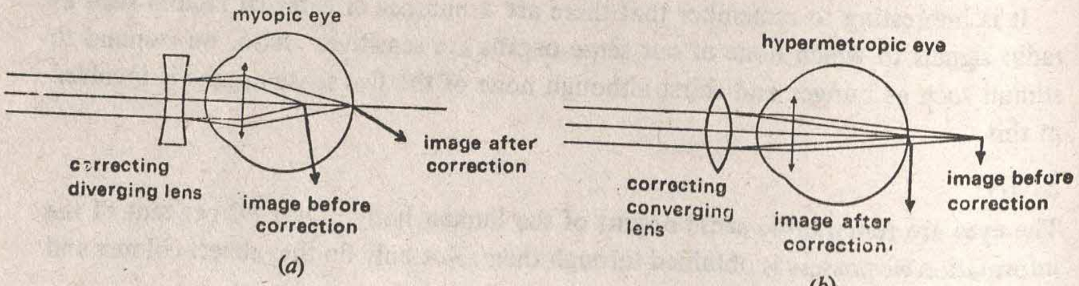


Diagram 120

Light falling on the cells of the retina sends impulses through the optic nerve to the brain. This makes us aware of illumination and darkness.



(*a*)

(*b*)

Diagram 121

HEARING

Our organ for hearing is the ear, which is perhaps next in importance to the eyes for gathering information. The ear has essentially three parts—the external, middle and inner ear. The ***pinna*** is the external part of this organ. In many animals, such as the dog, the pinna serves to concentrate and detect direction of the sound; in human beings this part serves no purpose except to protect the organ from external injury.

Sound waves travel through the opening and make the eardrum (***tympanic membrane***) vibrate. The middle ear consists of three small moveable bones called ***hammer, anvil*** and ***stirrup.*** They enable the external vibrations to be transmitted to the inner ear; the vibrations become amplified because the area of the little drum in the inner ear is much less than that of the external ear drum. The ***Eustachian tube*** leads to the throat so that the air pressure on either side of the tympanic membrane is kept almost constant; this enables the drum to vibrate efficiently.

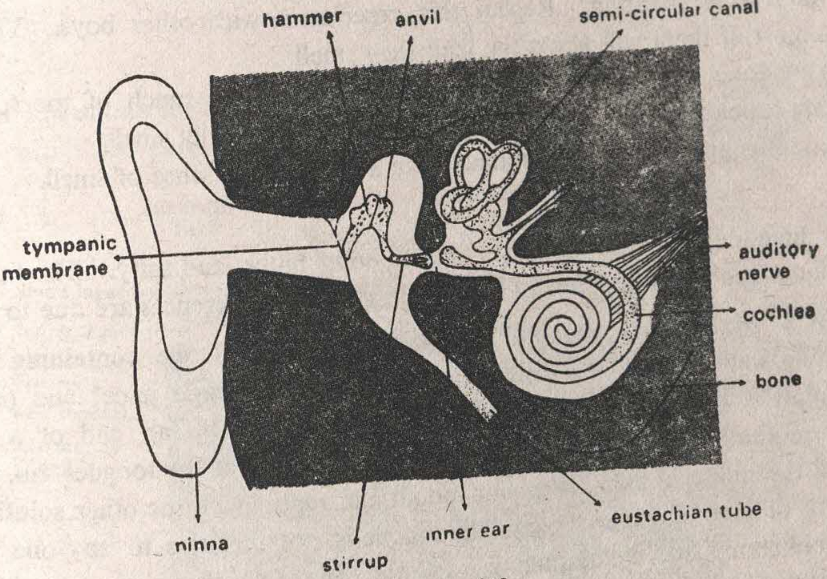


Diagram 122

The little drum is a window in a small chamber. The inner ear consists of (*a*) three fluid filled tubes called the ***semi-circular canals***; (*b*) a coiled fluid-filled tube called the ***cochlea***, and (*c*) the ***auditory nerve*** which connects them and carries the sensation of hearing to the brain. The vibrating stirrup causes liquid in the cochlea to vibrate; the nerve cells from the cochlea carry this sensation to the brain through the auditory nerve.

The inner ear also serves to maintain the balance of the body and a sense of position. The fluid in the semi-circular canal also vibrates due to changing position of the head and the rest of the body. The feeling of sickness during a bus or ship journey, or when you rotate quickly, is due to the movement of the liquid in the canals.

The normal human ear is sensitive to vibrations which have a frequency in the range of 20 to 20,000 vibrations per second (***hertz***). The range is remarkable, but the upper limit is greatly lowered due to age.

SMELL

The sense of smell is a chemical sense located in the nose. The moist nasal passage contains endings which lead to the brain and indicate smell. Human beings have a poorly developed sense of smell, yet much of the food we eat is liked or disliked by us due to the sense of smell rather than taste.

Activity 1. Ask a friend to close his eyes. Bring a fruit such as a mango near his nose so that he smells it clearly. Ask him to open his mouth and feed him small pieces of any other fruit such as banana, apple or apricot. Ask him to identify the fruit he is eating. Repeat this experiment with other boys. You will find that most of them will name the fruit they smell.

When we have a cold the nerve endings get blocked and much of the food we eat appears tasteless; thus part of what we call taste is actually smell.

Dogs, moths and some other animals have a very strong sense of smell.

TASTE

Basically there are four types of tastes—sweet, sour, bitter, and salty. The tastes of all food items are a combination of these four; all other differences are due to smell.

Activity 2. Make four solutions in different dishes: (*a*) one containing sugar dissolved in water; (*b*) one dissolved salt, (*c*) one fresh lime juice; and (*d*) one quinine solution. Rinse your mouth with distilled water. Dip an end of a clean glass rod in the sweet solution and touch it to four areas of the tongue—tip, back, centre and the sides. Again rinse your mouth and repeat with the other solutions.

You will observe that the whole of the tongue is not sensitive to any one taste. Diagram 123 shows that the shaded areas of the tongue which are most sensitive to the various tastes.

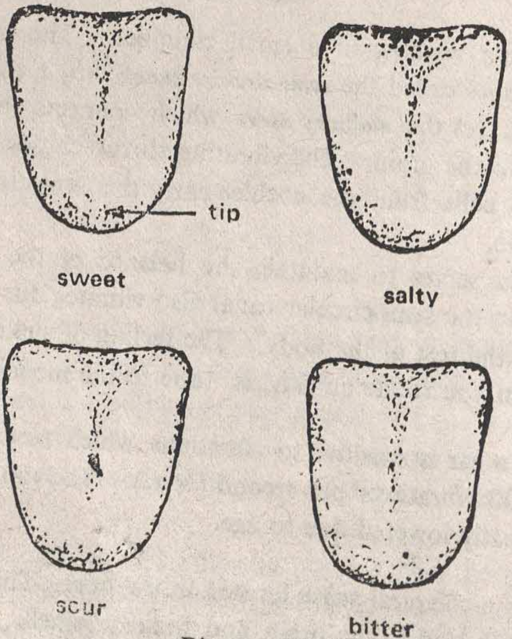


Diagram 123

The taste is obtained due to sense receptors called ***taste buds*** which are just below the surface of the tongue. A taste bud contains a group of nerve ends which are sensitive to dissolved substances. If you clean and dry the tongue and place on it dry particles of sugar or salt, you will not feel any taste. If the tongue is withdrawn in the mouth, the saliva dissolves the particles and the taste can be recognised.

TOUCH

Diagram 124 shows the vertical section of the skin. The skin structure is broadly divided into three parts. The ***epidermis*** contains the pigment responsible for skin colour. The dead cells on its surface peel off being replaced by younger cells underneath. Hair, nails and sweat glands are parts of the epidermis but reach far down into the inner layer called the ***dermis.***

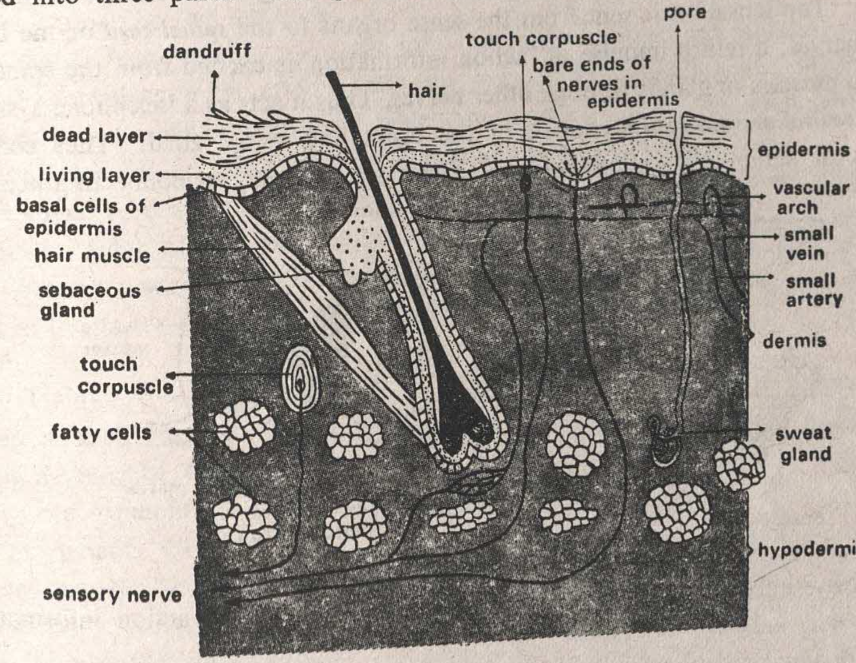


Diagram 124

The blood vessels in the dermis help to feed it and play an important role in temperature regulation. There are several sensory nerves which end in the epidermis. These are receptors for the sensation of touch, pressure, warmth, cold and pain. It may well be remembered that a particular nerve-ending is sensitive to only a particular stimulus. Nerve endings are not evenly distributed over the skin; there are more on the finger tips and palms than on other areas of our skin.

The skin has other functions also. It keeps out water and harmful bacteria; thick portions of the skin also protect us against exposure to friction. The skin produces sweat which evaporates to remove excess heat after strenuous physical activity. The sweat also removes toxic substances and this is thus an ***excretion.*** Ultra violet radiations transform cholestrol in the skin into vitamin D which is essential to our body. The skin also stores reserve fat in the dermis.

THE NERVOUS SYSTEM

Living organisms continually adapt and respond to their external environment. In order to respond to these stimuli quickly, it is necessary that sensations be rapidly sent to a central position where they can be sorted out and interpreted, and action taken by the body to preserve itself, or gain advantage over the environmental change. The sensation is sent from the sense organs to the ***spinal cord*** or the brain by the nerves; a return impulse or 'action information' is carried from the spinal or brain to muscles or glands through other nerves. Thus it acts as a 'telephone system'.

The ***central nervous system*** consists of the brain and spinal cord. They contain millions of nerve cells called ***neurons.*** These are the relay or connecting neurons which receive information from ***sensory neurons*** and pass on the action information through ***motor neurons.***

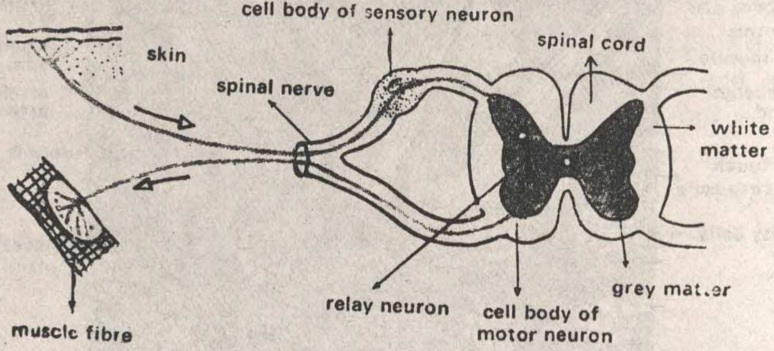


Diagram 125

An individual cell that carries impulses is called a neuron which contains a long fibre called an ***axon.*** The tree-like branchings which issue from the nerve cell are called ***dendrites*** (diagram 126). Each neuron acts as a channel for 'one-way traffic' for a nervous message:

Dendrite→cell body→axon

Some of the axons such as those in our legs and arms may be several centimetres long. Many axons are bundled together, like telephone cables, and these are called nerves.

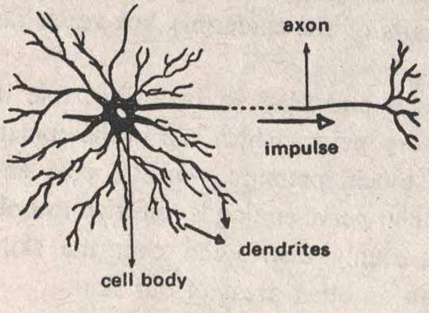


Diagram 126

The main nerve cell body is situated in the brain or spinal cord. It contains the nucleus and the protoplasm necessary for its life processes. If an axon is cut from the cell body, it cannot live long and dies within a few hours. The main cell may develop a new axon but this takes many months.

INVOLUNTARY MOVEMENTS

Activity 3. Sit on one edge of a table so that your legs hang freely. Let someone give you a quick and firm tap with the edge of his hand just below the knee cap. You will notice that the leg kicks forward. You do not have to make any conscious effort for this response.

No matter how you try, you cannot voluntarily contract the muscles of your heart, the intestines or the arteries; nor can you stop their contraction. The muscles of our nutritive organs are also not under our control. These are ***involuntary movements*** or ***reflex actions.*** Secretions by glands are also involuntary.

The spinal cord and the lower brain are the centre of these actions. The nerve impulses in reflex actions do not go to the upper brain; they travel from the sense organ through a sensory neuron to the spinal cord. Here they are quickly transferred to the motor neurons and carried to muscles or glands for corrective actions.

VOLUNTARY MOVEMENTS

Picking a book from a table, playing a game of football, or writing are examples of voluntary movements. The actions involved are delibrate and can be stopped at will. Such responses require the participation of the brain. The human brain is divided into three main parts — the ***cerebrum***, the ***cerebellum*** and the ***medulla.*** By electrical stimuli to various areas in the brain, it is possible to map out the various regions in the brain which control voluntary movements in different parts of the body (diagram 127).

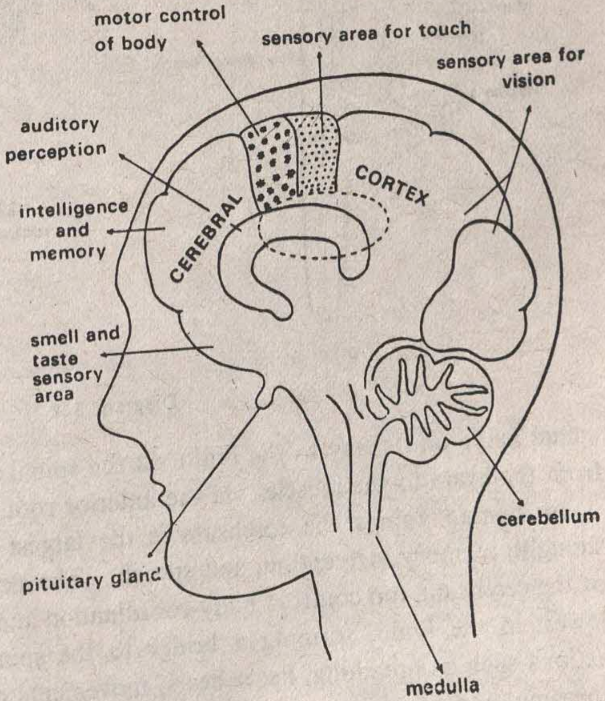
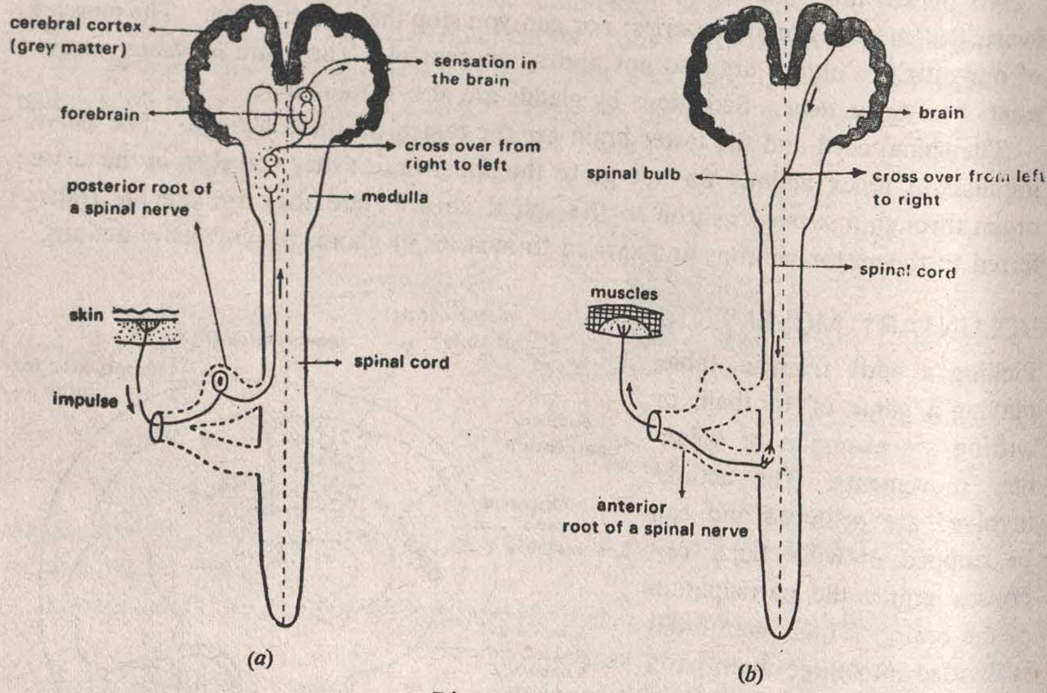


Diagram 127

Informations obtained in the course of medical operations has enabled surgeons to determine exactly the channels along which the nervous impulses pass from the muscles.

While information of the environment comes through the sense organs, conscious feeling is developed only in the ***grey matter*** in the brain. There is a loss of one or other of the conscious senses when one or other region of the cerebral cortex is damaged. This has also enabled scientists to fix the location of the senses in the various parts of the brain.

There are functional links between all the organs and the brain. These links are made by fibres in the nerves and the central nervous system. Diagrams 128 (*a*) and (*b*) show the path of a sensory impulse from the skin through the posterior root of the spinal nerve on its way to the brain via the spinal cord, and the path of a response from the brain to the muscles via the anterior root of a spinal nerve.



(*a*)

(*b*)

Diagram 128

In human beings the cerebrum is the largest part of the brain and controls thought, memory, perception, and speech. The cerebellum is under the rear part of the cerebrum and controls body-coordination and balance. The medulla is located lowest in the brain, forming a bridge to the spinal cord; it controls involuntary actions such as breathing, heart beats, movements of the digestive system, blinking, sneezing, and coughing.

The brain is continued into the spinal cord, which is about 50 cm long and 1 cm in diameter. The brain and the spinal cord are encased in three membranes called the ***meninges***. There are 12 pairs of cranial nerves arising from the brain These nerves form a link between the central nervous system and the rest of body.

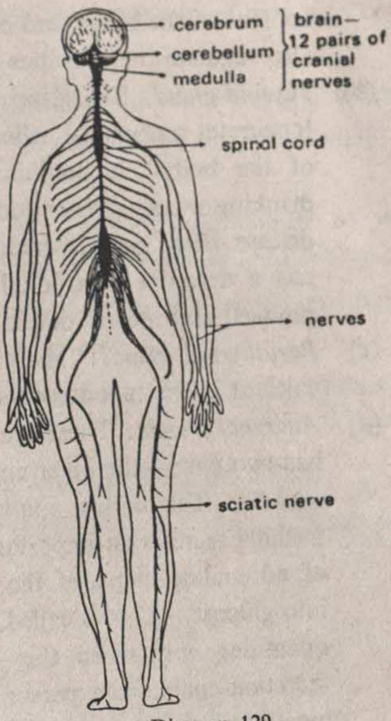


Diagram 129

THE ENDOCRINE SYSTEM

There exist some special glands in our body which secrete chemicals that control the internal working of our body. In the study of the digestive system we have studied three types of glands which have ***ducts*** or exit-tubes through which their secretions pour out. These glands are: (*a*) ***salivary glands***, which produce saliva; (*b*) the ***pancreas***, which produce digestive juices; and (*c*) the ***liver***, which secretes bile.

The endocrine system consists of ductless glands and produces secretions called ***hormones*** which mix directly into the blood. The various hormones travel in the blood to all parts of the body and are used by organs in varying quantities. Diagram 130 shows the position of various glands. The endocrine and nervous systems are very closely connected and work together in cooperation for the proper functioning of the body. The important ductless glands are as follows:

(*a*) *Pituitary gland*: This gland lies at the base of the brain, and is actually two-glands-in-one. The chemicals it secretes influence the growth of bones, blood pressure, and the water-

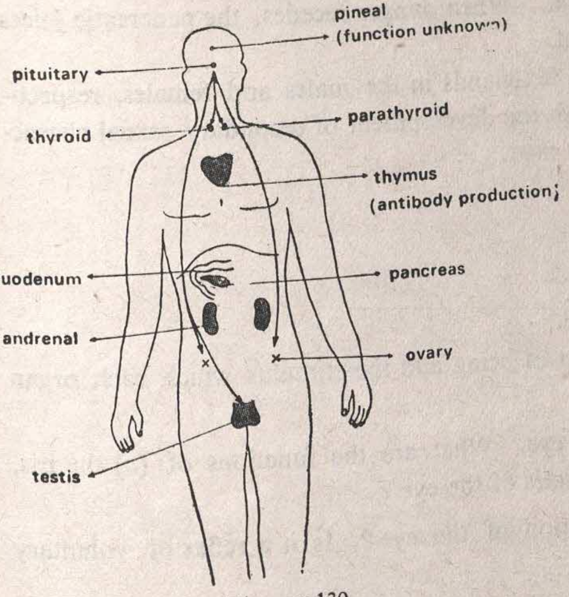


Diagram 130

content of the body, and controls fat production. Some of the secretions also regulate the activities of the thyroid and andrenal glands.

(*b*) *Thyroid gland*: The gland is H-shaped and lies on each side of the trachea. It secretes a chemical called thyroxine which tremendously speeds up action of the body. It contains iodine which is generally acquired through drinking water. When iodine is absent in drinking water, we contract the disease called ***goitre***, which causes swelling of the thyroid. A child which has a defective thyroid gland must be given thyroid-extract; otherwise its physical and mental development will be affected.

(*c*) *Parathyroid glands*: There are two glands which keep the proportion of calcium in the blood constant.

(*d*) *Andrenal glands*: These are two glands which lie close to the kidney. Each has two parts—the outer coat called ***cortex***, and the inner portion called the ***medulla***. The cortex controls the amount of sodium in our body. The medulla secretes an important chemical called ***adrenaline***. A larger secretion of adrenaline increases the sugar level in the blood by changing glycogen into glucose. This is called an emergency hormone and is secreted in large quantities only when the body is threatened by sudden danger. This secretion enables the person to prepare for 'fight or flight'. In this case breathing becomes rapid, the pupils of the eyes dilate, digestion ceases, and the skin becomes pale because the blood is diverted to the muscles; thus a lot of energy is made available for action.

We have already learnt that the pancreas secrete insulin which controls the level of sugar in the blood. When danger recedes, the pancreatic juices bring down the sugar content.

(*e*) *Testis* and *Ovary*: These are sex-glands in the males and females, respectively, and are concerned with the development of secondary sexual characteristics which we shall study next.

PROBLEMS

1. Name the sense organs of a human being and the stimulus which each organ perceives.
2. Draw a section-diagram of the eye. What are the functions of: (*a*) the iris, (*b*) the retina, (*c*) the ciliary muscles of the eye ?
3. What is meant by accommodation of the eye ? Is it a reflex or voluntary action ?

4. Name two common defects of the eye. Explain with the help of diagrams how these can be corrected.
5. With the help of a clear and simple diagram, show the various parts of the ear. What is the function of: (*a*) the semi-circular canals, (*b*) the Eustachian tube, (*c*) the middle ear ?
6. What are the four basic tastes we perceive ? How will you show by an experiment that smell enables us to perceive the flavours of the food we eat ?
7. What is a neuron ? Draw a simple labelled diagram of a neuron and indicate the direction in which a sensation travels through it.
8. What is the difference between a sensory neuron and a motor neuron ? What is a nerve ?
9. Name the different parts of the human brain and state their functions.
10. Name three glands with ducts and three glands without ducts. State the functions of the three ductless glands.

17

Man, Heredity and the Environment

We have so far studied some of the important functions carried out by the various organs and systems of the human body. As compared to the functions of the simplest organisms, such as Amoeba and Hydra, these functions are much more complex and their co-ordination is achieved in a most wonderful way. Human beings can make a large number of complicated responses to stimuli and possess a more highly developed central nervous system than any other animal. They also perform the function of reproduction, which is very different from the functions we have studied so far.

REPRODUCTION

Although reproduction is not essential for the survival of the individual organism, it is the only means of continuing and preserving the species. Life of one kind can arise only from pre-existing life of the same kind. There are a number of ways in which organisms reproduce their own kind.

Asexual reproduction is the process in which a new organism is formed only from one parent organism. For example, a parent Amoeba ***divides*** into two daughter Amoebae, and thus reproduces asexually. Asexual reproduction also takes place by means of ***spores***. For example, spores grow on a fern plant and each spore grows into a new fern plant. Multiple reproduction by means of spores also takes place in Amoeba. Yet another way of asexual reproduction is by the ***vegetative*** method. In this process a part of the parent plant becomes detached to give rise to a new plant. For example, an eye of a potato can give rise to a complete potato plant. Similarly, a stem cut from a rose bush grows into a new plant. A byrophyllum leaf detached from the parent plant gives rise to many new plants on its margin. Yeast, a micro-organism, produces buds which remain attached to the parent body until they can live on their own. Hydra, although an animal, can also reproduce in this manner.

Sexual reproduction, however, is much more common, and occurs in all species of organisms which possess sex. In this process two specialised cells from the same body, or from two different bodies, fuse together to produce a new organism. We have studied this earlier in the cases of plants and insects.

In sexual reproduction the male organism produces an active cell called the ***sperm***, whereas the female produces a passive cell called the ***ovum***. In simpler organisms these two types of cells appear to be identical, but in complex organisms they are very different in appearance. For example, in human beings the female ovum is spherical in shape and about 0.02 cm in diameter; it carries its own food reserves but cannot move by itself. The male sperm is about 0.005 cm long and has a small oval head with a long pointed tail; it consists almost entirely of nuclear material (diagram 133 *a* and *b*).

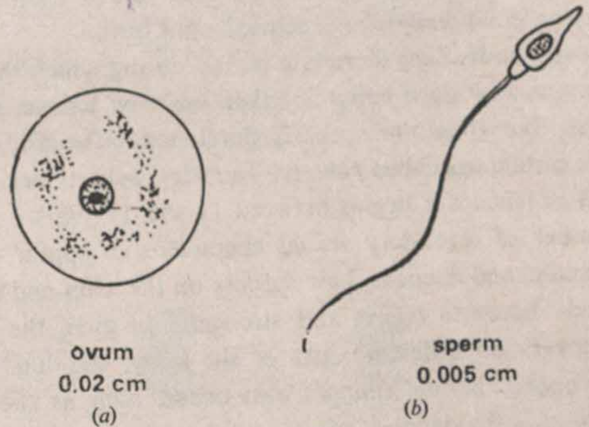


Diagram 133

GROWTH AND REPRODUCTION

Actually cells are always dividing by binary fission and multiplying in number during growth. In this process the daughter cells are identical to each other and to the parent cell; this process is called ***mitosis.***

The nuclei of cells contain thread-like structures called ***chromosomes.*** Chromosomes further contain bead-like bodies called ***genes.*** Genes are the units of ***heredity***, which means that they carry biological characteristics from the parents to the offspring. Human body cells each contain 46 chromosomes arranged in 23 pairs. When a cell divides by mitosis, each chromosome in it duplicates itself so that both the daughter cells possess 23 pairs of chromosomes each. All cells are capable of such division, which ensures that characteristics are passed down from one generation to the next one.

There are other special cells which are required during reproduction, and these are called the ***reproductive cells.*** They divide by a process known as ***meiosis*** to form ***gametes.*** The female ovum and the male sperm are gametes. Each gamete contains only 23 chromosomes, which is half the number of chromosomes present in a cell. Thus each gamete carries only half the biological information from its parent. When a female and a male gamete fuse, the process is called ***fertilization***; in this process a fertilized cell called a ***zygote*** is formed. The zygote contains 23 pairs of chromosomes, one-half of each pair being contributed by each parent. The zygote is the beginning of a new life. It is capable of division by mitosis, and begins growing into a new individual. The new cells it produces by mitosis specialize in performing different functions.

THE REPRODUCTIVE SYSTEM

The human reproductive system consists of organs in the male and female bodies to produce gametes, ducts through which they pass, and a chamber in the female where the developing child (***embryo***) is enclosed until birth.

In the life of every individual there is a period during which the body grows but cannot reproduce. A new born baby is either male or female, and possesses the reproductive organs but these are not fully developed. The ability to reproduce is acquired during a certain age called ***puberty***. In males, puberty begins between 11 and 15 years, whereas in females it begins between 11 and 13 years. At the beginning of puberty a number of secondary sexual characteristics appear. For example, in boys, the voice breaks and deepens, hair sprouts on the chin and other parts of the body, and the body becomes bigger and stronger. In girls, the breasts begin to develop, hair appears on different parts of the body, the hips widen, and the ***menstruation cycle*** begins. Mental changes also occur, such as the change of emotional attitudes towards the opposite sex.

Puberty begins with the secretion of certain hormones by the pituitary gland. These hormones activate the sex glands, the testes in the male, and the ovaries in the female.

THE MALE REPRODUCTIVE ORGANS

Diagram 134 shows the organs of the male reproductive system. These organs are

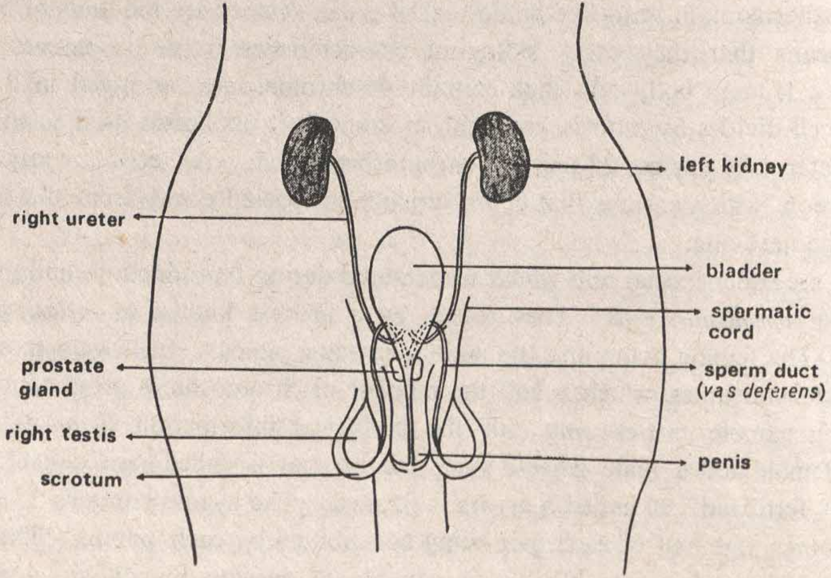


Diagram 134

the two ***testes***, which produce the sperms; the sperm ***duct (vas deferens)***, which carries the sperms out of the testes; and the ***penis***. The testes lie in the ***scrotum***, which is an outpocket of the body wall. The sperms pass through the duct and the ***urethra*** At the time of ejection from the penis, they mix with secretions (from associated glands) which form the ***seminal fluid***. This fluid provides the sperms with a medium to swim in and nourish themselves for some time.

THE FEMALE REPRODUCTIVE SYSTEM

The female reproductive system (diagram 135) consists of two ***ovaries***, which produce the ova; the ***oviducts***, through which the ova travel; the ***uterus*** (womb); and the ***vagina***.

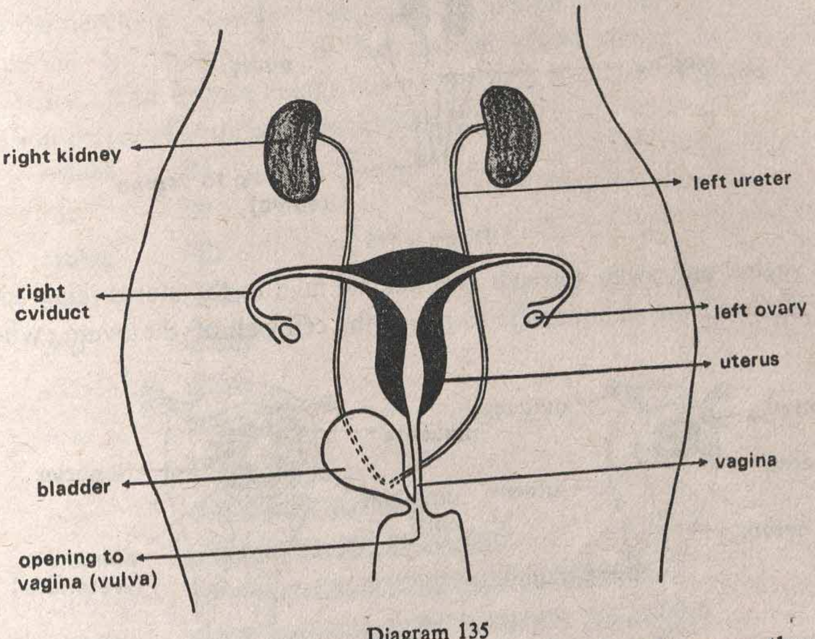


Diagram 135

The ovary is made of blood vessels, connective tissues, and many thousands of egg cells. Only about 500 of these egg cells become mature ova. These egg cells are dormant till the onset of puberty. After puberty has been reached, the two ovaries release one ovum alternately about once every 28 days. The released ovum travels through the oviduct to the uterus; this process is called ***ovulation***. At the same time, the lining of the uterus becomes thickened and soft. If the mature ovum is not fertilized by a sperm entering the oviduct from the vagina, the uterus sheds the ovum, the lining of soft tissue, and some extra blood. This process of releasing these waste materials through the vagina is called menstruation. It normally occurs a few days after ovulation, once every 28 days, and lasts for about 3 to 5 days.

FERTILIZATION AND DEVELOPMENT

Sperms produced in the male reproductive system pass by the way of the penis into the vagina during ***copulation***. During each act of copulation millions of sperms enter the vagina and swim through the seminal fluid to the uterus (diagram 136). Only one of the sperms can manage to pierce the cell wall of the ovum ; when this

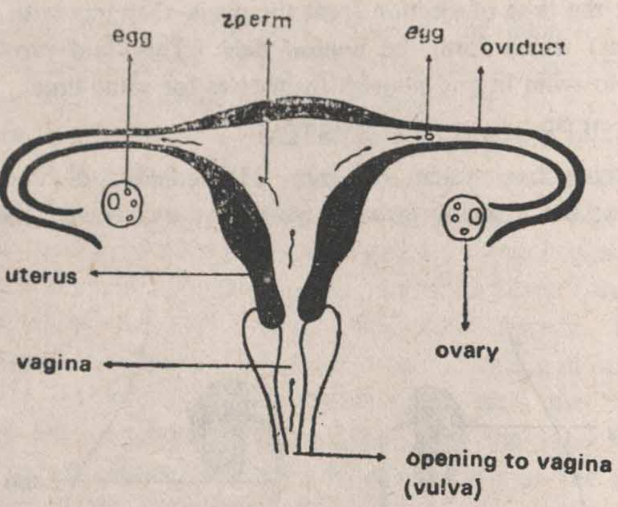
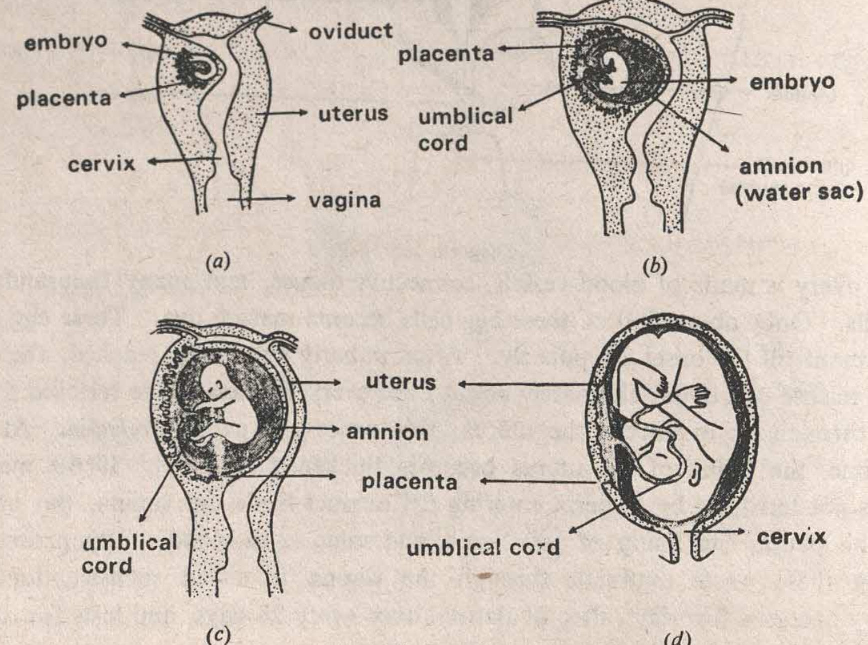


Diagram 136



(*a*) (*b*) (*c*) (*d*)

Diagram 137

happens, the ovum is said to be fertilized. As soon as a sperm penetrates the ovum, a membrane is formed around the fertilized egg cell to prevent any more sperms from entering it. The membrane-covered cell is now called a ***zygote.*** The sperms which cannot fertilize an ovum eventually die.

The zygote enters the uterus and undergoes rapid cell division (mitosis). It is embedded in the soft lining of the uterus, and develops small projections from its body, which are called ***villi.*** It attaches itself to the ***placenta***, through which the embryo receives nutrition from the blood vessels in the wall of the uterus. Using this nutrition the embryo develops the tissues and organs of a new human being. Because of the presence of the child in the womb, the menstrual cycle is interrupted, and the woman is said to be pregnant. Diagram 137 shows the various stages in the development of the embryo in the mother's womb.

The period of development of the embryo within the mother is called the ***gestation period.*** For human beings this period is 266 days. Diagram 138 shows the gestation periods for different mammals.

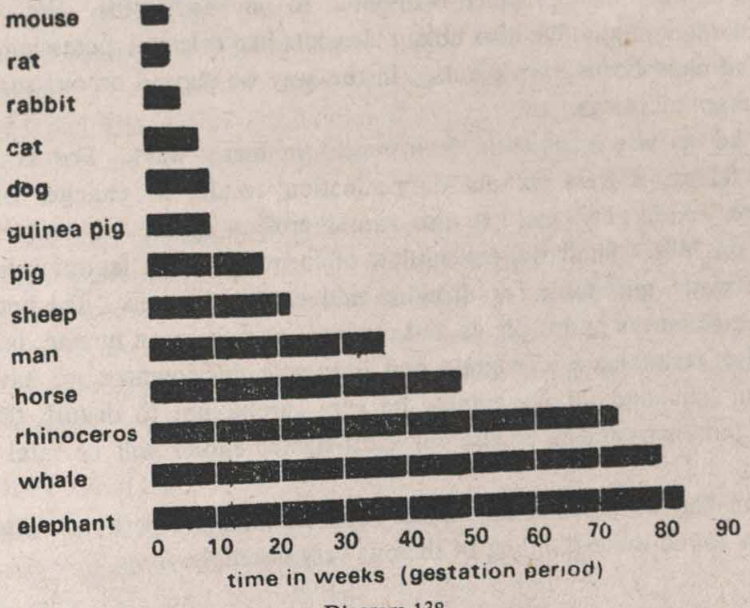


Diagram 138

During the period of internal growth the human embryo tremendously increases in mass, from about one-millionth of a gram to about three kilograms; that is, its weight increases 3×10^9 times. Therefore, during pregnancy, the mother must receive all essential nourishment.

Around the time of birth, the walls of the uterus undergo rhythmic contractions and force the baby out of the womb. The tissue joining the embryo to the placenta, called the ***umblical cord,*** is cut in order to separate the mother from the child. The child is a new human life; very much like its parents, but not identical to them; an individual that will develop and grow to find a unique place in the world.

In the first few weeks the baby is almost entirely dependent on its mother for its food. Its nourishment comes from the mother's ***mammary glands***, which secrete milk containing the substances necessary for the child's survival.

MAN AND HIS ENVIRONMENT

Our lives are considerably influenced by the conditions we live in. The physical factors in our environment which affect us are temperature, humidity, light, quality of soil, the technological products of our civilization, etc. The biological factors affecting us are the plants and animals around us.

We have learnt earlier that human beings are totally dependent on plants and animals for the supply of their food. Plants are the primary sources of food for human beings and other animals. The oxygen required for respiration is obtained from the atmosphere. Plants replace the oxygen we use up, during photosynthesis. Nitrogen is another element which is essential to our body cells. We obtain this from the plants we eat. We also obtain elements like calcium, potassium, sodium, sulphur, and phosphorus from plants. In this way we depend on our surroundings for many essential things.

Living beings also affect their environment in many ways. For example, the large-scale felling of trees without discrimination results in changes of rainfall, temperature, soil-fertility, etc. It also causes erosion of topsoil, and may cause landslides on hills. Similarly, the outflow of chemicals from factories into rivers makes the water unsuitable for drinking and causes diseases. The uncontrolled smoke from chimneys harms plants and causes lung diseases in human beings. In the pursuit of technological progress and economic development we have greatly changed our surroundings. We must be very careful not to disturb the natural balance in our environment, or else our short-sighted efforts will be fatal for later generations.

Two other factors which affect human happiness and prosperity are diseases and the soil. A sound understanding of these is very desirable.

DISEASES

Disease is a state of departure from normal health. It includes functional disorders, as well as such injuries as broken bones. There are various reasons for diseases of the human body.

Infectious diseases such as influenza are caused by various ***microbes*** as well as by larger organisms. The smallest organisms are ***viruses***. They can live and multiply only within living tissues; outside, they appear to be non-living. Viruses are too small to be seen under a light microscope.

Bacteria are larger microbes that can be seen under a light microscope. They can grow within and outside living organisms; e.g., they grow on agar jelly. ***Fungi*** are larger than bacteria, and have a more complex structure. Yeast, for example, is a kind of fungus.

Diseases are also caused by the deficiency of certain nutrients; e.g., scurvy and rickets are caused by lack of vitamins. Some diseases are transferred by parents to their children through genes, and such diseases are said to be hereditary; e.g., haemophilia. The malfunctioning of glands can also lead to diseases; e.g., goitre and diabetes.

SPREAD OF DISEASES

Many infections, particularly those of the throat and the lungs, are caught during inhalation. The germs of these spread in the air around us from the exhaled breath, sneezes, and sputum of infected persons.

The spread of such diseases as dysentery, cholera, and typhoid occurs due to the contamination of food and water by microbes. Boiled drinking water, clean utensils, washed hands, and the avoidance of food cooked unhygenically, are some of the precautions in the case of these diseases. The ***tetanus bacterium*** thrives in cowdung and dirt and enters our bodies through open cuts and wounds. The disease they carry can be fatal if the anti-tetanus serum is not administered in time.

Another important method of transmission of diseases is by animal ***vectors*** (carriers). There are two types of vectors. Mechanical vectors carry infected matter on their bodies; e.g., houseflies carry germs of dysentery, typhoid, etc. Biological vectors are those within whose bodies infectious organisms carry out some stage of their development; mosquitoes are the biological vectors of malaria and yellow fever.

PREVENTION OF DISEASES

Our body has several lines of defence against the microbes which cause diseases. Some bacteria are destroyed by saliva, gastric juice, and bile. Some are filtered out by the nasal hair, and the cavities in mouth and throat, etc., when air is breathed in. The epidermal cells of the skin also prevent the entry of germs. The exposed eyeballs are protected by the secretion of tears.

Should germs enter the body through open wounds, food, water, etc., they are attacked by certain blood cells (white blood corpuscles) and destroyed. Some infectious germs are neutralised by ***antibodies***, which are produced by the bone-marrow and the lymphatic tissue. However, ***immunization*** becomes necessary against strong infection.

At birth a child carries antibodies obtained from its mother's body. These protect it from infection during the first few weeks of life.

Many illnesses such as measles, mumps, and chicken pox, occur only once in our bodies; during that first infection, our bodies develop antibodies which prevent the same infection from occuring again.

Inoculation using a ***serum*** from another person or animal which has already developed antibodies can also give us rapid but brief immunity. This form of inoculation is used against such diseases as diphtheria and plague.

Another form of the development of antibodies is by inoculation using a mild form of an infection or its toxin. For example, immunization against smallpox is now possible by inoculation with cowpox germs.

SOIL

Since plants are the basic food of human beings and animals, the soil on which they grow is of great importance. The soil has four uses for a plant. It holds the plant firmly in position. It supplies the plant with the water it requires. It contains the mineral salts used by the plant to manufacture food. It provides the oxygen necessary for root respiration. Because of these vital functions, it is very important for us to take care of soil. The topsoil may be washed away by floods or even excess water. The subsoil may be exhausted of the mineral salts required by the plants, in which case we have to use fertilizers and practise crop rotation. The fertility of the soil also depends on soil bacteria, and so we have to use manure regularly. The weather and climate are the other important factors which affect the quality of the soil.

CONCLUSION

As we have seen, the interdependence of many factors determines the balance maintained in nature. This ecological balance must be maintained very carefully. In the past 10,000 years, or so, man has dominated the biological world. In the past 300 years, the technological progress he has made has enabled him to gain considerable control over the environment. We have exploited many of the natural resources around us. How well the ecological balance is maintained depends on how wisely we use these natural resources. The quality of life of later generations depends on our actions.

PROBLEMS

1. What is meant by sexual and asexual reproduction ? Give one example of each. Also give one example of an organism which can reproduce in both ways.

2. What are the two different modes of cell division ? What are the functions of these two types of division ?
3. Name the reproductive organs of the human male and female, and state the function of each organ.
4. Trace the growth and development of a human child from the time of the fertilization of the ovum to the time of birth.
5. What are the secondary sexual characteristics in human beings ? When do they appear ?
6. (*a*) How is the growth of a copper sulphate crystal in a copper sulphate solution different from the growth of a mammal ?
   (*b*) How is human reproduction different from the production of nuts and bolts in a factory ?
7. How does a person get infected with malaria ? How can it be prevented ? How can it be cured ?
8. Name two other infectious diseases and state how they can be prevented and cured. How does the body prevent the penetration of microbes ?
9. Name two important gases in the atmosphere. How is their proportion changed by plants and animals ? Why does their proportion not change significantly over long periods of time ?
10. If the balance in nature is disturbed by removing a link in the food chain of plants and animals, serious consequences may result. Describe an example of this happening due to an action of man.

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